Developer's Guide

SILMA®
Division of Adept Technology, Inc.

© Copyright March, 1997 Adept Technology, Inc.

ALL RIGHTS RESERVED

This material is the property of Adept Technology, Inc., and contains confidential information. No part of this publication may be reproduced, published, stored in a retrieval system, or disclosed to others without prior written permission from Adept Technology, Inc.

The use of general descriptive names, trade names, trademarks, etc., in this manual, even if they are not especially identified, does not mean that such names, as understood by the Trade Marks and Merchandise Marks Act, may accordingly be used freely by anyone.

The material contained herein is subject to change without notice.

Table of Contents

Using this Manual

Manual Conventions xv
Notation xviii

Chapter 1: Introduction to the SIL Language

SIL Language Overview 1-2
SIL Compared to Pascal 1-2
The SIL Programming Environment 1-3
The SIL Runtime Model 1-4
Environments 1-5
Values 1-6
Expressions 1-7
Terms 1-8
Statements 1-9
Definitions 1-11
Globals 1-11
Types 1-12
Functions and Procedures 1-13
Variable Declarations 1-15
Accessing Help 1-16

Chapter 2: Object-Oriented Programming in SIL

Data Types 2-1
Constructed Types 2-2
Lists 2-2
Arrays 2-3
sarrays 2-4
Functions and Procedures 2-4
System-Defined Types 2-4
Strings 2-4
String Comparisons 2-5
String Conversions 2-5
lstrings 2-5
User-Defined Types 2-6

Records 2-7
lrecords 2-7
Advanced Data Types 2-8
ntype 2-9
Supertypes 2-11
lispobs 2-11
universals 2-13
Applying Procedures 2-15
Applications 2-16
C Data Types 2-17
C Records and C Arrays 2-17
C Strings 2-19
C Constants at Build Time 2-21
Casting 2-21
SIL Constants 2-22
Polymorphism 2-23
Classes and Inheritance 2-24
Classes 2-25
Inheritance 2-26
Specialization and Generalization 2-27
The specialize_to Operator 2-27
Views 2-28
Abstract Classes 2-29
Installation of Methods 2-31
Additional Methods Primitives 2-33
The mnode Class 2-33
Concurrency 2-34
Tasks 2-35
Delay 2-35
Start and Run 2-36
Tickers 2-37
Semaphores 2-38
Pipes 2-40
Processes 2-41
Closures and tclosures 2-42
Closures 2-43
tclosures 2-46

Using Closures and tclosures to Customize G Code Translators 2-47
Symbols 2-49

Chapter 3: Working with SIL Code

Protection 3-1
Input/Output 3-2
Reading from the Keyboard 3-2
Writing to the Screen 3-5
Reading and Writing to a File 3-5
EOF 3-7
Code Organization 3-8
The Cim Tree Structure 3-9
Loading SIL Code 3-11
Creating a New Product 3-12
Compiling SIL Code 3-14
Creating New Versions 3-17
Including Modules and Products in the Product Administration Panel 3-18
Adding New Modules 3-18
Adding New Products 3-18
Dependency Management 3-19
Modules 3-19
umodules 3-20
“if” Syntax 3-21
“Support Only” Builds Areas 3-21
Application Solutions Header Module 3-21
Patching in Interpreted Code 3-22
Debugging 3-23
Debugging in Menu Mode 3-29
Calling C Code from SIL 3-29
Sample `.c` and `.h` Files 3-30
Passing Data Types to C 3-34

Chapter 4: Geometry in Soft Machines

Understanding Soft Machines Geometry 4-1
Geometric Terms 4-1
Shape 4-2
Frame 4-2

Geometric Units 4-3
Position 4-4
Cartesian Description 4-5
Cylindrical Description 4-6
Spherical Description 4-7
Orientation 4-8
Yaw-Pitch-Roll 4-10
Euler Angles 4-12
Equivalent Angle-Axis 4-13
Poses 4-16
Geometric Operators 4-17

Chapter 5: Modeling Using SIL Commands

The model Data Type 5-1
Modeling Constructors 5-1
Curves 5-2
Conics 5-3
Surfaces 5-4
Cap 5-4
Facet 5-4
Plane Surface 5-5
Grid Surface 5-5
Surface of Revolution 5-6
Tube as rvsurf 5-6
Funnel as rvsurf 5-7
Tabulated Cylinder 5-7
Rational B-Spline Surface 5-7
Coons Surface 5-8
Geometric Constructors 5-9
Conic Constructors 5-9
Bezier Curve Constructor 5-10
Bezier Patch Constructor 5-11
Conic Surface Constructors 5-11
Evaluating Parametric Shapes 5-11
Parametric Curves 5-11
Parametric Surfaces 5-12
Wireframe Models 5-13

Volume Models 5-13
Cylinder 5-13
Block 5-13
Pipe 5-13
Cone 5-14
Frustum 5-14
Model Operators 5-14
The invert Operator 5-14
The glue Operator 5-15
The moveto Operator 5-16
The imoveto Operator 5-16
The moveby Operator 5-16
IGES Conversions 5-16
Converting IGES Files to Soft Machines Models 5-17
Converting Soft Machines Models to IGES files 5-18
Modeling Examples 5-19

Chapter 6: Modeling NC Machines

General Overview of Soft Machines 6-2
NC Simulator 6-2
Developing an NC Simulator 6-4
NC Machine Data Class 6-7
Defining NC Coordinate Systems 6-8
Axes Convention 6-8
NC Coordinates Versus SILSPEC Coordinates 6-10
Defining NC Reference Coordinates 6-11
NC Coordinates in Joint Space 6-14
Determining Simulation Strategy 6-18
Attaching a Tool Library to an NC Machine 6-18
Machine Status 6-19
G and M Tables 6-21
Machine Pendant Panel 6-21
Summary 6-22

Chapter 7: Modeling NC Tooling

The Tooling Assembly 7-2
Cutting Tool 7-7

Tool Holder 7-11
Tool Changer 7-14
Tool Library 7-17
Setting Cutter Offsets 7-25
Setting Offsets for End Effectors (Inverse Kinematics) 7-26
Setting Offsets in Joint Vectors 7-28
Assigning Additional Properties 7-29
Collision Detection 7-29
Material Removal 7-30
Spindle On/Off 7-32

Chapter 8: NC Tasks
Creating SIL Tasks for NC Machines 8-2
Machine Independent Tasks 8-2
Machine Dependent Tasks 8-8
Tool Changers 8-8
Forward Kinematics Moves 8-15
Canned Cycles 8-18
Constructing and Customizing G and M Tables 8-23
Grouping G Codes 8-23
Error Logging and Reporting 8-29
Error Log 8-30
Recording Movies 8-30

Chapter 9: Constructing the G Code Translator
Architecture of a G Code Translator 9-2
Converting G Code into SIL Data Type 9-3
gcode_info Data Type 9-3
G Code Reader 9-5
Reading a G Code Statement 9-6
Reading a G Code File 9-7
Executing G and M Codes 9-10
Subroutines and Synchronized Cutting 9-12

Chapter 10: Using First Cut
Introduction to First Cut 10-1
Product Overview 10-4

Operation and User Interface 10-5
First Cut Simulation Overview 10-6
User Interface General Features 10-7
First Cut Functions 10-8
Introduction to the Windows Used for First Cut Functions 10-8
Using the Metal Removal Setup Panel 10-9
Defining the Stock 10-9
Setting the Cutter Display 10-9
Simulate Mode 10-9
Metal Removal Window *10-10*
Geometry Window *10-11*
Information Display 10-13
Feed 10-13
Coolnt 10-14
D 10-14
R 10-14
H 10-14
CL-ID 10-14
X, Y, Z 10-14
I, J, K 10-14
Metal Removal Window Functions 10-15
File Menu 10-15
The Read NC File Panel 10-16
Input Name Conventions and Pre-Processing 10-17
Output Name Conventions 10-17
Scroll Bars 10-18
The *Read WIP file…* Selection 10-19
The *Write WIP file…* Selection 10-19
The *Write image file* Selection 10-20
The *Use playback file…* Selection 10-21
The *Read batch file…* Selection 10-21
The *Exit* Selection 10-21
Model Menu 10-22
The *Create stock* selections 10-23
Creating a Box 10-23
Creating a Cylinder 10-24
Creating a Profile Sweep 10-25

The *Read SLA file…* Selection 10-27
Creating a Fixture 10-28
Changing the Type of a Model 10-28
Deleting an Object 10-28
The *Translate…* Selection 10-29
The *Rotate…* Selection 10-29
Scaling a Model 10-30
Control Menu 10-31
Defining the Default Cutter 10-32
Defining the Default Tool Axis 10-32
The *Cutter limits…* Selection 10-33
Setting the Maximum Cutting Feedrate 10-34
The *Subset range…* Selection 10-35
The Subset box… Selection 10-35
The Use entire NC program Selection 10-36
The Multi-axis Switch 10-36
Auto Menu 10-36
The Change color at cutter change Switch 10-37
The …and repaint Switch 10-37
The Solid cutter Switch 10-38
The Continuous display of cutter Switch 10-38
The Write image at cutter change Switch 10-38
The Write image at error Switch 10-38
The Enhance when writing image Switch 10-39
The Record Switch 10-39
The Ignore holder and shaft Switch 10-39
Windows Menu 10-40
Help Menu 10-40
Geometry Window Functions 10-41
View Menu 10-42
Dynamic Menu 10-43
Setup Mode Selections 10-44
The Rotate XY Selection 10-44
The Pan Selection 10-44
The Zoom Selection 10-44
The Rotate Z Selection 10-44
Simulation Mode Selections 10-45

The Rotate Selection 10-45
The Move light Selection 10-45
The Zoom Selection 10-46
Fit Menu 10-46
Fit 10-46
Center 10-46
Colors Menu 10-47
Display Menu 10-48
The Show axes Switch 10-48
The Show cutter Switch 10-48
The Shadows Switch 10-48
Modes Menu 10-49
The Enhance Switch 10-49
The *Section…* Selection 10-50
The Compare Switch 10-51
The *Rotate…* Selection 10-51
The Translucent Switch 10-53
The *Reset* Selections 10-54
Measure Menu 10-55
The *Point…* Selection 10-55
The *Time…* Selection 10-56
The *CL-ID…* Selection 10-58
The *Remove chips* Selection 10-59
The *Volume…* Selection 10-60
Conclusion 10-61
Getting the Most From First Cut 10-62
Performance 10-62
Choosing an Optimal View 10-63
Accuracy 10-63
Multiple Viewports 10-63
File Management 10-63
Dithering 10-64
Getting the Most from the CL File Conversion Program 10-64
Cutter Definitions 10-65
Physical Tool Changes 10-65
Post Processor Statements 10-66
Converting a CL File (cltoncv) 10-66

File Conversion Program cltoncv 10-67
The NCV File and MES File 10-68
The Control File Option 10-69
Syntax for Each Control File Definition 10-69
Stock Definition 10-69
Stock Box (specified) 10-69
Stock box - Auto 10-70
Stock Profile Sweep 10-70
Fixture Definition 10-70
Cutter Default Parameters 10-72
Cutter Default Definition 10-73
Cutter Types 10-73
Minimum Cutter Diameter Default 10-73
Minimum Cutter Length Default 10-73
Processing Defaults 10-74
Tool Axis Default 10-74
Feedrate/RAPID Override 10-74
Cutter Facets 10-74
Example Control File 10-75
NCV Input Data Formats 10-76
NCV File Format Specifications for Custom CL File Conversion 10-77
Basic Structure for File Formats 10-77
Numeric Convention 10-78
Major Word Table 10-79
$$ 10-79
BOX 10-79
BREAK 10-79
CALL/CXCIR or CALL/ATPCIR 10-80
CBOX 10-80
COOLNT 10-81
CUTTER 10-81
CYCLE 10-81
CYL 10-82
ENVECT 10-82
FBOX 10-82
FCBOX 10-83

FCYL 10-83
FEDRAT 10-84
FINI 10-84
FROM 10-85
GODLTA 10-85
GOHOME 10-85
GOTO 10-86
LOADTL, TOOLNO, TURRET, TMARK, GOHOME,
STOP 10-86
MULTAX 10-87
NSIDES 10-87
PARTNO 10-87
PPRINT 10-88
PPRINT BREAK 10-88
PPRINT COLOR # 10-89
PPRINT HOLDER NAME 10-89
PPRINT IMAGE 10-90
PPRINT TRUEC (or PPRINT TRUE C) 10-90
PPRINT WIP NAME 10-91
RAPID 10-91
REMARK 10-91
ROTABL 10-92
SPINDL 10-92
SPROF 10-94
SPPROF 10-94
STVECT 10-94
STOP 10-94
TLAXIS 10-95
TMARK 10-95
TOOLNO 10-96
TURRET 10-96
CYCLE Words 10-97
CYCLE Formats 10-97
CYCLE Parameters 10-97
Common Options 10-99
[, RAPTO, depth] 10-99
[, DWELL, 10-99

DRILL Cycle 10-100
FACE Cycle 10-101
TAP Cycle 10-102
BORE Cycle 10-103
REAM Cycle 10-104
DEEP Cycle 10-105
Examples of Usage 10-108
BRKCHP Cycle 10-109
THRU Cycle 10-111
CSINK Cycle 10-112
Sample NCV File 10-114
Sample Control File 10-117
Sample Stock Definition in NCV File 10-118
SLA File Format 10-118
G-Code Input 10-120
G-Codes Supported 10-120
Other Codes Supported 10-121
Restrictions 10-121
Processing 10-121
Special Data Files 10-122
CATIA File Input 10-124
Tool Holders 10-125
Format of ncvholder.lib File 10-126
Sample ncvholder.lib File 10-127
Form Cutters 10-128
First Cut Tutorial 10-130
Program Components 10-131
Tutorial Prerequisites 10-132
Simulation Session - Part One 10-134
Reading the NC File 10-134
Metal Removal Window *10-137*
Geometry Window *10-138*
Display of Coordinate System Axes 10-138
Cutter Display Button 10-139
View Selection 10-139
Creating Multiple Views 10-140
Changing the View 10-140

Commence the Simulation 10-142
Automatic Action Control 10-143
Setting Color Options 10-144
Setting up Recording 10-144
Setting Automatic Check Points 10-145
Rapid Motions 10-146
Stopping or Slowing Down the Simulation 10-146
Viewing in Translucent Mode 10-147
Error Messages 10-147
End of Simulation 10-147
Chip Removal 10-148
Simulation Evaluation 10-149
Repaint 10-152
Sectioning the Part 10-152
Rotating the View of the Part 10-153
Rotate Dialog 10-153
Flipping the View of the Part 10-154
Zooming in on the Part 10-154
Light Source and Shadows 10-155
Playing Back the Recording of the Simulation 10-156
Simulation Session - Part Two 10-158
Comparison of the As-Machined Part with the Design Part 10-158
Read an NC File for Comparison 10-158
Read in SLA File of the As-Designed Part 10-160
Run the Simulation for the Comparison 10-162
Compare the As-Machined Part with the As-Designed Part 10-163
Other Production Facilities 10-165
Saving an Image of the Session 10-166
Viewing Saved Images 10-167
Exiting the First Cut Simulation Session 10-168

Index

Using this Manual

Manual Conventions

The following sections describe conventions which have been used in this manual to denote specific concepts.

For the following, **this typeface** is used:

- booleans
- statements
- commands
- variables
- object names
- operators

Example: **mk_rctcurve (pts: darray of pnt3dr; n: integer);** is an operator.

The SIL Prompt

The SIL prompt is shown by: SIL>. When you see the prompt, it means that the code following it can be entered exactly as shown. If the line following the SIL> prompt line is in `this font`, this is the result of the command. Example:

```
SIL>  monthly_salary(team1_leader);
3541.666748
```

In this example, you would enter **monthly_salary(team1_leader);** at the SIL> prompt. After you press <RETURN>, `3541.666748` would be displayed in the shell window.

SIL Syntax

Sections showing syntax of more than one line have a box around them. The code sometimes contains variables indicated by <> symbols.

```
function f(x:A;<a1>:<type1> ....):<result-type>;
  var …
  begin
  …
  end;
```

SIL Code Examples

The examples are printed in gray boxes. They include explanatory text and code. The code may be entered as shown.

Example 1.1

Assignment statements:

```
x := sin(y); x := x + 1; table[6] := 0; employee.salary := x;
```

Procedure calls:

```
writeln('hello', '...', 'world');
deposit(account, 50.00);
```

Rules

Rules are shown with a dark gray title bar and a box around the rule.

Rule 1.1

```
<sequence> := begin <statement>; …; <statement>; end;
```

Windows

Windows that are part of the display are indicated in *Italics*. Examples: *Quick Pick Window* and *Graphics Window*.

Filenames

`This typeface` is used for filenames. Example: **`default.sil`** is a file.

Keys

Keyboard keys are indicated by the "<>" symbols enclosing the key in capital letters in THIS TYPEFACE. Example: <RETURN> is a key.

The Top Bar

Pulldown menus from the top bar are indicated with bold letters in **This Typeface**. Example: **File** is a pulldown menu.

Panels

Panels are indicated with This Typeface. Example: Collision Detection is the title of the panel that is displayed when you choose *Collision Detection...* from the **Utilities** pulldown menu.

Pulldown Selections and Commands

Selections from the pulldown menus, commands and command buttons are indicated with *Italics in this Typeface*. Examples: *Install* is a selection from the **File** menu, *Apply* is a command.

Toggle Choices

Toggle choices are shown with a ◆ symbol in front of the label. Example: ◆ Checks is a toggle choice.

Switches

Switches are shown with a ❑ symbol in front of the label. Example: ❑ Show Reference Frame.

Fields and Messages

The label and the information in the field are in this typeface. Example: Edge Length displays 1.0 in its field.

Messages, such as instructions and error messages that pop up or are displayed in the panels are quoted using this typeface. Example: Pick any edge of an object.

Notation

This manual uses simplified grammatical rules (which resemble BNF) to describe syntactic forms. This section describes these rules completely.

These rules use the following form:

<A> ::= exp

where **<A>** is a non-terminal symbol and **exp** is a string of terminal and non-terminal symbols. Interpret the above rule to mean that all occurrences of the non-terminal symbol **<A>** can be replaced by the string **exp**. The goal of a rule such as that described above is to derive syntactically valid strings of non-terminal symbols by repeatedly applying all available rules to a given string until all non-terminal symbols have been replaced.

Five conventions are associated with the rules used in this manual. These conventions provide readers with a means of denoting specific types of symbols and of writing rules in an abbreviated fashion.

1. Rules with the same left-hand side:

   <A> ::= exp1
   <A> ::= exp2
   <A> ::= exp3

   can be rewritten in a single line as:

   <A> ::= exp1 | exp2 | exp3

2. Rules with the same right-hand side:

<A1> ::= exp
<A2> ::= exp
<A3> ::= exp

can be rewritten in a single line as:

<A1>, <A2>, <A3> ::= exp

3. Rules in which one right-hand side is a substring of another:

   <A> ::= ac | abc

   can be rewritten as a single rule:

   <A> ::= a[b]c

   Here **[b]** indicates that the string **b** is optional.

4. Recursive forms can be written with rules such as:

   <A> ::= e | e<A>

   or:

   <A> ::= e…e

   Here, **e…e** means that **A** can be replaced by a string of one or more **e**'s.

5. A non-terminal symbol is any character string enclosed by angle brackets (<>):

   <parameter list>
   <function application>
   <etc>

All other character strings are terminals.

We can describe all numerals with the following set of rules:

<numeral> ::= [-]<non-zero digit>[<digit> … <digit>] | 0

where

<non-zero digit> ::= 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

<digit> ::= 0 | <non-zero digit>

The numeral -204 can then be derived as follows:

<numeral>
-<non-zero digit><digit><digit>
-2<digit><digit>
-20<digit>
-20<non-zero digit>
-204

Chapter 1

Introduction to the SIL Language

Although the Soft Machines menus provide most of the commands you need, you can also create your own commands by writing programs in a language called SIL. Using the SIL language, you can develop your own Soft Machines applications which take advantage of the capabilities that SIL offers. Soft Machines, in fact, is a SIL application.

SIL is a powerful general-purpose programming language that lies at the heart of Soft Machines and supports advanced programming methods such as object-oriented programming, concurrent programming, and meta-programming.

This manual is intended as a reference manual for software developers to develop custom applications for Soft Machines using the SIL language. Specifically, the following topics are covered:

- Constructing software models of machines based on kinematics models (SILSPECS)
- Modeling NC tooling
- Developing NC related procedures, functions and tasks
- Customizing G and M codes
- Developing custom G code translators

This chapter provides an overview of the SIL language, including a simplified model of SIL's runtime environment.

SIL Language Overview

The layers of SIL implementation are arranged in the following fashion:

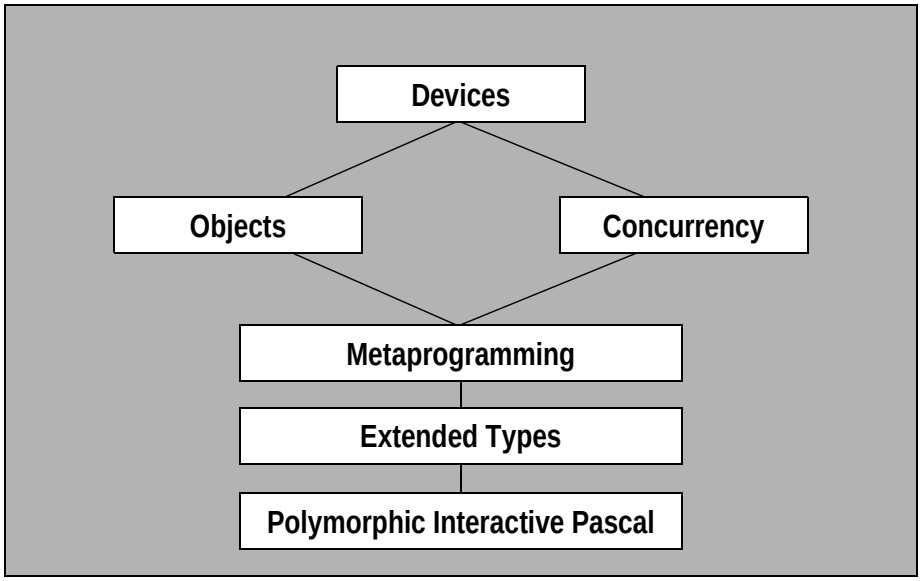


Figure 1-1 The SIL language

SIL Compared to Pascal

SIL and Pascal share many syntactic features. Programmers familiar with Pascal, but new to SIL, can get started by treating SIL as an interactive implementation of Pascal. SIL syntax is a superset of Pascal syntax, and all of the control structures have their usual Pascal meanings—basic data types such as reals, integers, booleans, and records have standard behavior. The difference between the two languages emerges when examining pointer types—SIL maintains pointer structures in a Lisp or SmallTalk-like heap, so that pointer management is different from (and simpler than) Pascal.

Still another feature which distinguishes SIL from Pascal is its polymorphism. SIL is polymorphic in the sense that the same symbol may be used to denote functions of differing input types. For example,

the function **double** may be defined both for reals and points, without conflict. This is known as **static polymorphism** (SIL supports other kinds as well). Because the decision of which function variant to use is made at compile time, no performance slowdown occurs.

The SIL Programming Environment

The SIL programming environment, like that of Lisp or SmallTalk, is interactive. Any legal expression can be typed or cut and pasted into the SIL> prompt, including new functions, type definitions, or global assignments. Typing or pasting in expressions results in these new entities being added to the current programming state. In Text Mode, the mouse buttons have different functions (such as cutting and pasting text), which are defined by the operating system.

Uncompiled SIL code is executed by a fast pseudo-code based interpreter. It is possible to compile SIL code, also; to do this, the code is translated first into C and then to binary using the host machine's C compiler. The performance of compiled SIL code is similar to that of corresponding code written directly in C (or Pascal). Interpreted and compiled code may be freely mixed—compiled functions may be replaced at will by modified interpreted variants, allowing fast bug fixing and testing.

The *SIL Window* can be used to enter SIL language commands while retaining access to the menus and panels. The *SIL Window* is displayed under the *Graphics Window*.

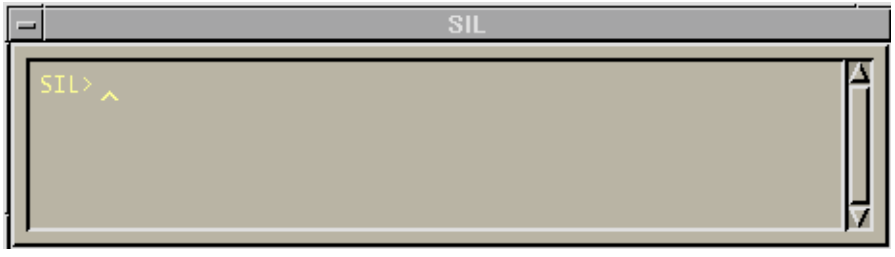


Figure 1-2 The *SIL Window*

You can also change to Text Mode to enter SIL language commands. In Text Mode, you have full editing capability and direct access to the operating system.

Change to Text Mode by selecting *Exit Menus* from the **File** pulldown menu. The menus are disabled and the SIL> prompt is displayed in the shell window that you used to start Soft Machines.

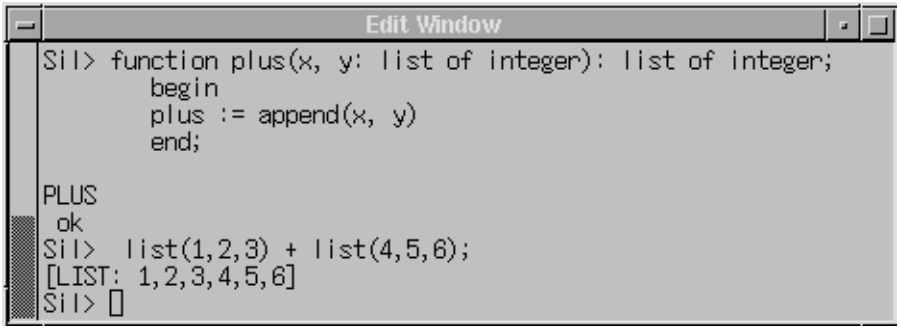


Figure 1-3 Shell window example

Enter **menus();** at the SIL> prompt to restore access to the menus. If the system has become disabled, enter **r();** at the Error> prompt to reset the system.

The SIL Runtime Model

This section contains the following topics:

- *Environments*
- *Values*
- *Expressions*
  - Terms
  - Statements
  - Definitions

SIL is an interpreted language. This means that an expression is read from a file or the keyboard, and is passed to the SIL interpreter which then computes the value of the expression. The computed value is passed to a printer which writes it to a file or the screen, and the cycle repeats.

Figure 1-4 shows a representation of the relationships between the components of the SIL runtime model.

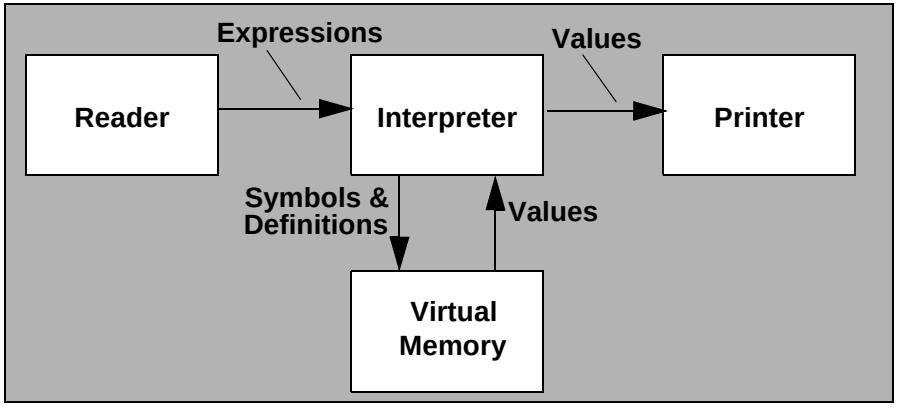


Figure 1-4 The SIL runtime model

Environments

Environments are either permanent or temporary. The permanent environment is called the **global** environment. The global environment contains bindings for

- All type names
- Function/procedure names
- Global variables

Local environments contain bindings for

- The parameters of a function/procedure
- The local variables of a function/procedure

Values

Values, or data objects, are the scalars and data structures such as numbers, strings, records, and arrays that inhabit the computer's memory and represent abstract entities in the problem domain. The generic term used in SIL to describe all of these objects is **lispob** (which was derived from **LISP OB**ject).

Lispobs may be classified into data types, or, to put it the other way around, a data type can be viewed as a collection of similar **lispob**s. Knowing the data type of a **lispob** is important. For example, this information is used to compute the amount of memory space required to store the **lispob** or to detect inconsistencies in a SIL program.

SIL data types fall into one of three broad categories:

- System-defined types:
  integer, real, boolean, string, …
- Constructed types:
  list types, array types, function types, …
- User-defined types:
  record types, classes, …

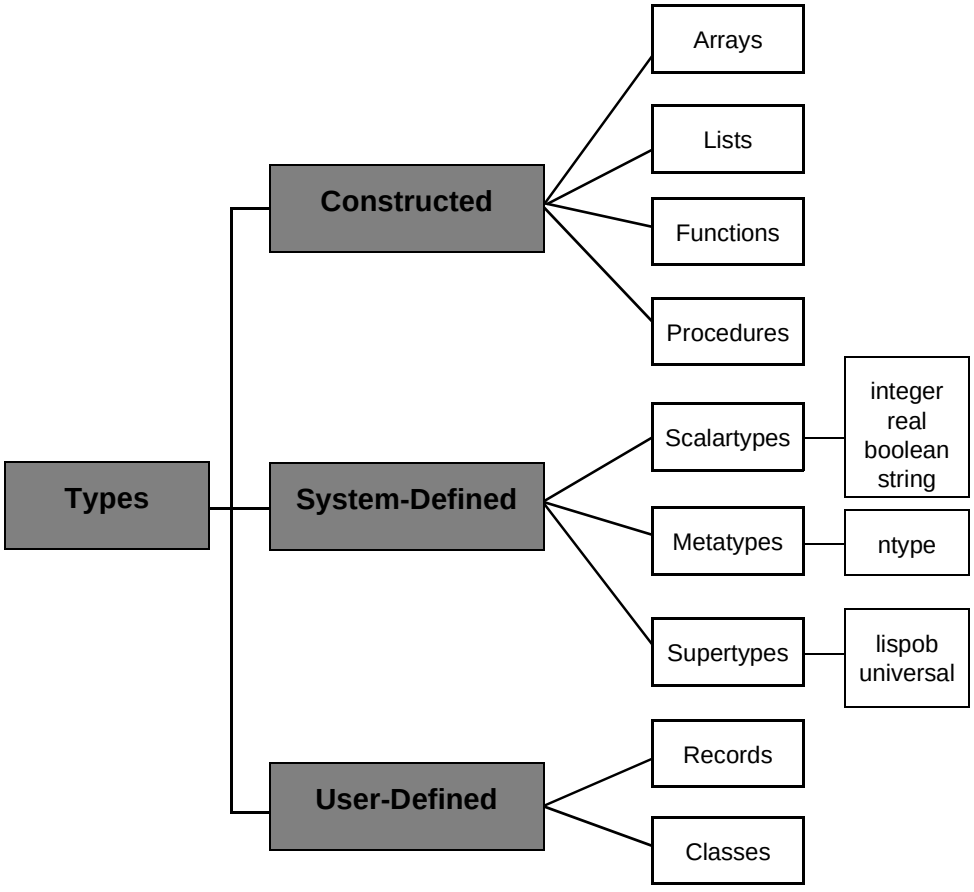


Figure 1-5 Data type classifications

Expressions

NOTE This section describes features in SIL which are identical to Pascal, so you may want to skim, or even skip, this section if you know Pascal.

There are three types of SIL expressions: **terms**, **statements**, and **definitions**.

Terms

There are three types of terms in SIL: **constants**, **variables**, and **function applications**.

Example 1.2	
constants:	**2, -1.1, pi, "a_symbol, 'a string', nil, true, false**
variables:	**x, active_nc_machine, part_prog_name**
applications:	**sin(pi), max(2, x), mod(trunc(sin(x)), 50)**

Other examples of function applications include **infix operators**, which use the form:

<term> <operator> <term>

Other examples include special syntax for accessing fields of records and components of arrays, as illustrated in Example 1.3.

Example 1.3	
Infix operators:	**x + y, x / y, x and y, x > y, x = y**
Unary operators:	**-x, not x**
Array components:	**mount_point[x]**
Field selectors:	**active_nc_machine.tlib**
Mixed:	**mount_point[x].holder**

Statements

Generally, a statement alters an environment. Statements can be grouped into **atomic** statements and **compound** statements.

Atomic statements are assignment statements and procedure calls.

Example 1.4

Assignment statements:

```
x := y + 1;x := sin(y);tab[6] := 0.;
machine.tlib := lib_name;
```

Procedure calls:

```
writeln('hello', '....', 'world');
install(object_name, file_name);
```

Compound statements are built up from atomic statements using statement constructors. There are three categories of statement constructors: conditionals and case statements, sequences, and iterations.

Sequences are groups of statements that are combined into a single statement by bracketing them between the key words **begin** and **end**.

Conditional statements are in the form of **IF** statements (see Example 1.5) or **case** statements (shown in Example 1.6)

Example 1.5

```
if x >= 0 then y := x;

if x >= 0 then y :=x else y := -x;

if test1 then
   begin
      if test 2 then
           do_something()
      else
           do_nothing();
   end
else
   do_nothing();
```

Example 1.6

```
Case s of
   '!ABORT!': menu_return();
   '!INIT!': init_nc_cell();
   'SELECT MACHINE':
      begin
         select_nc_machine();
         init_nc_cell();
      end;
   'SELECT TOOL LIB':
      begin
         select_nc_tool_lib();
         init_nc_cell();
      end;
   'SIMULATE': call(ncv_simulation_imenu);
   'MACHINE PENDANT': nc_machine_pendant();
   'MODEL TOOLING': call(model_tooling_imenu);
   'SAVE CELL SETUP': save_nc_setup();
   'MISC': call(misc_functions_imenu);
end;
```

There are several types of **iteration** statements: **repeat**, **while**, and **for**. The **repeat** and **while** statements behave similarly.

Example 1.7

A **repeat** statement can be used to check the validity of a user input:

```
{ Repeat reading string until end of file }
repeat
   readln(fn, s);
   ncv_batch_jobs_list := cons(s, ncv_batch_jobs_list);
   end_of_file := eof(fn);
until end_of_file;
```

continued on next page

Example 1.7 (continued)

An example of **while**:

```
{ While not end of file, read string and construct list }
while (not(eof(fn))) do
   begin
      readln(fn, s);
      ncv_batch_jobs_list := cons(s, ncv_batch_jobs_list);
   end;
```

An example of **for**:

```
for s in ncv_batch_jobs_list do
   begin
      writeln(fn, s);
   end;
```

Definitions

SIL uses five categories of definitions:

- Global variable definition
- Variable declaration
- Type definition
- Procedure definition
- Function definition

Globals

The syntax for defining a new global variable or re-defining an old global is

```
<variable> == <term>
```

This statement assigns the value of **<term>** to **<variable>**, even if **<variable>** was not previously declared or was assigned a value of a different type.

Example 1.8

x == 22;

assigns the value 22 to the variable **x**.

x == 'hello world';

changes the value of **x** to the string **hello world**.

Types

To define new data types, use the following syntax:

type <type definition>; …; <type definition>;;

where

<type definition> ::= <type name> = <type>

In this case, **<type>** is a term which evaluates to a data type. Notice the extra semicolon at the end of the declaration. This tells the interpreter not to expect more type definitions.

Example 1.9

We can define several types in a single type definition:

```
type
    years = integer;
    dollars = real;
    gcode_status =
            lrecord
                ok: boolean;
                stmt_no: integer;
                err_msg: string;
            end;;
```

continued on next page

Example 1.9 (continued)

```
type
    gcode_closure =
        tclosure(gcode_status, nc_machine,
                 gcode_info);
    g_function =
        lrecord
            group: integer;
            cl: gcode_closure;
        end;
    g_table = darray of g_function;;
```

Functions and Procedures

The format of function and procedure definitions follows Pascal syntax (illustrated in Example 1.10).

Example 1.10

```
count == 0;          { count is a global variable }
procedure inc_count();
begin
   count := count + 1;
end;
procedure dec_count();
begin
   count := count - 1;
end;
procedure reset_count();
begin
   count := 0;
end;

procedure display_employee(e: employee);
begin
   writeln(e.name);
   writeln('salary = ', e.salary);
   writeln('age = ', e.age);
end;
```

continued on next page

Example 1.10 (continued)

```
procedure NCV_top_handler(s:string);
begin
   case s of
      'MOVE': do_mv();
      'MODELING': do_md();
      'LAYOUT WORKCELL': do_lw();
      'INSTALL': do_in();
      'SAVE': do_sv();
      'DEVICES': call(xxcreate_models_imenu);
      'MODELING': call(xxcreate_models_imenu);
      'LAYOUT WORKCELL':
                  call(ncv_layout_workcell_imenu);
      'NCV MENUS': call(ncv_module_imenu);
   end;
end;
```

Example 1.11

```
function square(x: real): real;
begin
   square := x * x;
end;

function average(x, y: real): real;
begin
   average := (x+y)/2;
end;

function absolute_value(x: real): real;
begin
   if x >=0 then
      absolute_value := x
   else
      absolute_value := -x;
end;
```

continued on next page

Example 1.11 (continued)

```
function distance(p1, p2: point);
begin
   distance :=
   sqrt(square(p2.xc - p1.xc) +
   square(p2.yc - p1.yc) +
   square(p2.zc - p1.zc));
end;
```

The primary difference between a procedure and a function is that a function returns a value, whereas a procedure operates purely by side effect.

Variable Declarations

The format of a variable declaration is

var <variable declarations>; ...; <variable declarations>;;

where **<variable declarations>** is a list of variables followed by a type expression:

<variable declarations> ::= <variable list> : <type>

Variable lists are variables separated by commas:

<variable list> ::= <variable>, ..., <variable>

In the global environment, be sure to place a double semi-colon at the end of the variable declaration so that the interpreter will not expect more variable declarations.

Example 1.12

Several variables can be declared in a single declaration:

```
var
    x,y,z: integer;
    a,b,c: real;
    i,j,k: darray of integer;
    vmc: nc_machine;;
```

SIL will initialize integers to 0, reals to 0.0, and arrays to length 0 arrays. You should not, however, depend on this—you should always initialize your own variables.

Accessing Help

SIL includes a simple help facility:

```
help <name>;
```

The **help** command prints out all of the variants of the given name, their types, and the name of the file in which they were defined.
Example 1.13 shows part of the information printed out for the **plus** command in a Soft Machines state.

Example 1.13

```
SIL> help plus;
type = FUNCTION(INERTIA_MATRIX, INERTIA_MATRIX,
INERTIA_MATRIX) from file:
        ~/cim/builds/nbot_ops37/s/v_inertia.sil
        protection: 0
type = FUNCTION(JV,JV,JV) from file:
        ~/cim/builds/nbot_typ26/s/v2mech2.sil
        protection: 0
type = FUNCTION(JVR,JVR,JVR) from file:
        ~/cim/builds/nbot_typ26/s/v2mech2.sil
        protection: 0
type = FUNCTION(AV,AV,AV) from file:
        ~/cim/builds/nbot_typ26/s/v6mech.sil
        protection: 0
type = FUNCTION(GCOORD,GCOORD,GCOORD) from file:
        ~/cim/builds/device8/s/d2gcoord.sil
        protection: 0
```

The **help** command also prints out type definitions.

Chapter 2

Object-Oriented Programming in SIL

This chapter contains the following topics:

- *Data Types*
- *Advanced Data Types*
- *C Data Types*
- *Casting*
- *Polymorphism*
- *Classes and Inheritance*
- *Concurrency*
- *Closures and tclosures*
- *Symbols*

Data Types

This section contains these topics:

- *Constructed Types*
- *System-Defined Types*
- *User-Defined Types*

The SIL Type System uses the Pascal typing structure as a starting point and expands on it. SIL provides types which are dynamically allocated, and automatically collected from a heap. These types include dynamic lists, arrays, strings, trees, and a special type, **lispob**.

All SIL data are of type **lispob**. **lispob**s can be partitioned into data types, and data types can be classified as constructed, system-defined, or user-defined types. This section describes the basic data types, including lists, arrays, records, strings.

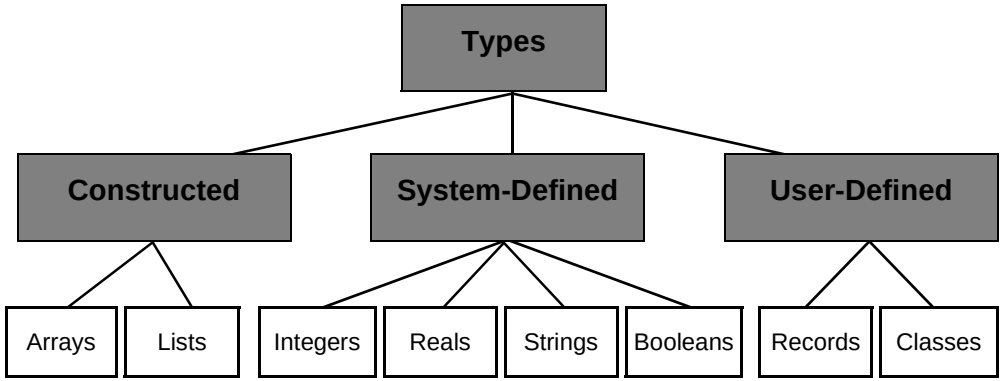


Figure 2-1 Basic SIL data types

NOTE The complete SIL data type structure is shown in Figure 1-5, “Data type classifications” on page 1-7.

Constructed Types

Constructed types are built from existing types using type constructors. Some type constructors are **list_of**, **array_of**, **function** and **procedure**.

Lists

A **dynamic list** is a sequence of objects, all of the same type, which can grow and shrink during program execution. You can define and manipulate dynamic lists using the traditional Lisp operations: **car**, **cdr**, and **cons**.

list_of(integer) is the type of all integer lists.

The base type of the type **list_of(integer)** is **integer**. Notice that **list_of(list_of(integer))** is another constructed type with base type **list_of(integer)**. **list of integer** is the alternative syntax for **list_of(integer)**.

The **list** operations ensure that the base type of a list is well-defined. For example, the call

```
list(1, 2, 'hello world')
```

results in a type mismatch error, since all of the arguments are not of the same type. This seems fairly straightforward until we consider **empty lists** (lists with 0 members). What is the base type of an empty list? To solve this problem in SIL, you need to declare the base type whenever you create an empty list. A call to the empty list constructor has the form

emptylist(<type>)

where **<type>** is any type expression and indicates the base type of the empty list returned by this call. Of course, you must be able to determine whether or not a list is empty. To check whether or not a list is empty, use the predicate

null(<list>)

which returns **TRUE** if **<list>** is an empty list (of any base type).

Arrays

array_of(integer) is the type of all arrays of integers (regardless of size).

The base type in this case is **integer**. **darray of integer** is the alternative syntax for **array_of(integer)**. Like lists, SIL arrays are also dynamic. This means that arrays can be created during program execution. The call

array_create(<type>, <integer>)

returns an array of base type **<type>** indexed from **0** to **<integer>**. As in Pascal, if **v** is an array and **i** is a valid index, then **v[i]** is an expression whose value is the element of **v** with index **i**, and **v[i] := <term>** sets the index **i** component of **v** to be the value of **<term>**. As with lists, the type of **<term>** must match the base type of **v**, or a type mismatch error will result.

Unlike Pascal, SIL functions can return arrays as values.

sarrays

An **sarray** is a dynamically-allocated array, which can grow and shrink during program execution. You can add items to the **sarray**, and the **sarray** will automatically resize itself to fit the new elements. As with standard arrays, if **s** is an **sarray** and **i** is a valid index then **s[i]** returns the **i**th element of the sarray, and **s[i] := <term>** sets the index **i** component of **s** to be the value of **<term>**. Also, like arrays, **<term>** must match the base type of **s**, or a type mismatch error will occur.

The command

emptysarray(<type>)

returns a new **sarray**.

Functions and Procedures

- **function(real, integer, integer)** is the type of all functions that take two integer inputs and return a real output. Integer division is a function in this type.
- **procedure(real, integer)** is the type of all procedures which expect a real-valued and integer-valued input.

System-Defined Types

SIL system-defined types include the basic scalar types: **integer**, **real**, **boolean**, **string**.

Strings

Strings are dynamic in SIL.

Example 2.1

The definition:

msg == 'hello';

assigns the length 5 string **hello** to the variable **msg**. Later, we can reassign **msg**'s value by:

msg := 'goodbye';

In the above example, we assign a length 7 string (**goodbye**) to the same variable. Memory allocation for the additional characters is handled automatically. Of course shorter strings can be assigned to **msg**:

```
msg := 'bye';
```

String Comparisons

In SIL, users make lexicographical comparisons using the syntax

<string> < <string>

Additionally, we can compare strings using: **<=**, **>**, **>=**, **=**, and **<>**.

The **match** operator compares strings that may contain wildcards.

String Conversions

A string composed of numerals can be converted to an integer by using

string_to_integer(<string>)

Conversely, an integer can be converted to a string by using

integer_to_string(<integer>)

Similarly, we can convert reals to strings and back with

real_to_string(<real>)

and

string_to_real(<string>)

lstrings

Consider the following assignments:

```
x := 'abcdffg';
x := substring(x,2,3);
```

These assignments result in the value of **x** being **'bcd'**. The SIL interpreter will construct a new three-character string for the second assignment. Repeated assignments like these can result in an inefficient consumption of memory. To combat this problem, SIL provides an **lstring**, which can be defined as follows:

```
lstring = lrecord
    length: integer;
    contents: string;
end;;
```

Primitive operations on **lstring**s:

```
function mk_lstring(x: string): lstring;
function mk_lstring(x: string; n: integer): lstring;
function copy(x: lstring): lstring; { Allocates a new string }
function substring(x: lstring; n,m: integer): lstring;
function select(x: lstring; n,m: integer): lstring;
function equal(x: lstring; y: string): boolean;
function select(x: lstring; y: integer);
procedure lowercase(x: lstring);
procedure concat_onto(y: string; x: lstring);
function lstr_to_str(x: lstring): string;
function to_lstring(x: string): lstring;
procedure float2lstr(y: real; ls: lstring);
function find(cnx: string; lnx: integer; cny: string;
              lny: integer): integer;
function find(x: string; y: string): integer;
function find(x: lstring; y: string): integer;
function find(x: lstring; y: lstring): integer;
procedure concat_onto(x: lstring; n: char);
```

User-Defined Types

User-defined types are created by type definitions:

type <name> = <type expression>;;

Any kind of type expression can be used in a type definition.

Two of the most commonly-used of these types, **record**s and **lrecord**s, are described in the following sections.

Records

Records are always defined within the scope of a **type** definition at the top level. The syntax follows Pascal:

```
type
    <name> = record
        <field>, … <field>: <type>;
        …
        <field>, … <field>: <type>;
    end;;
```

where **<field>** and **<name>** are identifiers.

Unlike Pascal **record**s, defining a **record** in SIL automatically defines a constructor function which enables you to create **record**s in a single statement. The name of the constructor function adds the prefix **mk**_ to the name of the **record**.

Unlike Pascal, SIL functions can return **record**s as values.

lrecords

Record parameters are passed by value. This means that a function/procedure which is passed a **record** as an input actually makes a private copy of the **record** input before it modifies any of its fields.

In SIL, **record**s are used to represent non-mutable entities and **lrecord**s are used to represent mutable structures. An **lrecord** is just a pointer to a **record**—**lrecord** parameters are passed by reference rather than by value. This means that a function/procedure only gets a pointer to an **lrecord**, not a private copy.

Advanced Data Types

This section contains these topics:

- *ntype*
- *Supertypes*
- *Applications*

SIL system-defined types include the basic scalar types: **integer**, **real**, **boolean**, **string**. But SIL also provides some fairly exotic types. For example, internal representations of SIL expressions and their components are also ordinary SIL data objects which can be manipulated by SIL programs the same way that scalars can. These are called **metaobjects**, and the types to which they belong are called **metatypes**.

Another category of useful system-defined types is the **supertypes**. If we think of types as sets of values, then all types can be regarded as subsets of the supertypes. The two supertypes are **lispob** and **universal**.

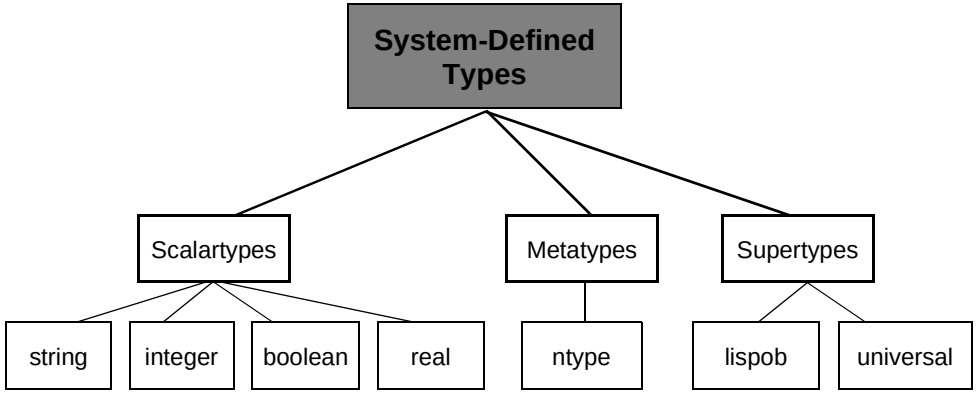


Figure 2-2 System-defined type classifications

ntype

The type **ntype**, the "type of all types", can be defined grammatically by

```
<ntype> ::= <dtype> | <polymorphic type>
<dtype> ::= <primitive type> | <constructed type>
<primitive type> ::= <user defined type> | <atomic type>
<atomic type> ::= <scalar type> | <metatype> | <supertype>
<scalar type> ::= integer | boolean | char | string | real
<metatype> ::= id | sconst | ntype | tform | iform | net | event | …
<supertype> ::= universal | lispob
<constructed type> ::= array_of(<dtype>) | list_of(<dtype>)
        | sarray_of(<dtype>)
        | closure(<return type>,<input type>,...,<input type>)
        | tclosure(<return type>,<input type>,...,<input type>)
<polymorphic type> ::= function(<return type>,<input
                                    type>,...,<input type>)
        | procedure(<input type>,...,<input type>)
        | task(<return type>,<input type>,...,<input type>)
<input type> ::= <dtype>
<return type> ::= <dtype>
```

Notice that **ntype** appears to be a member of itself. However, it is really the syntactic expression **ntype** that is a member of the data type **ntype**, so Russell's paradox is avoided.

The following is a partial list of the primitive operations on **ntype**. The names of the functions are self-documenting:

```
function is_primitive (n:ntype):boolean;
function is_reptyp (n:ntype):boolean;
function is_array (n:ntype):boolean;
function is_list (n:ntype):boolean;
function rep_of(n:ntype):ntype; { assumes n is represented type }
function list_subtype(x:ntype):ntype;
function subtype(x:ntype):ntype;
function subtypes(x:ntype):list_of_ntype;
function mk_list_type(x:ntype): ntype;
function mk_array_type(x:ntype): ntype;
function is_function (n:ntype):boolean;
```

Assume **x** = result type, **y** = input types:

```
function mk_function_type(x:ntype;y:list_of_ntype): ntype;
                    { assumes a real function type is the input: }
function is_task(x:sconst):boolean;
function is_closure(x:sconst):boolean;
function is_tclosure(x:sconst):boolean;
function input_types(x:ntype):list_of_ntype;
function result_type(x:ntype):ntype;
```

Supertypes

SIL supertypes include **lispob** and **universal**. Supertypes are ordinary data types; they can appear in type definitions, variable declarations, and as input or output types for functions. What makes supertypes "super" is that SIL data objects of any type can be legally cast to a supertype using SIL's **as_type** operation.

Example 2.2

```
3 as_type lispob;
2.7 as_type lispob;
'Good Morning' as_type lispob;
list(1,2,3,4) as_type lispob;

3 as_type universal;
2.7 as_type universal;
'Good Morning' as_type universal;
list(1,2,3,4) as_type universal;
```

lispobs

The type **lispob** is the SIL type whose values include all SIL values (**lispob** was derived from **LISP OB**ject). **ob** is short for **lispob**, i.e., **ob == lispob**. Example 2.3 illustrates how to use **ob** to resolve SIL typing restrictions.

Example 2.3

Suppose we want to write a function to check whether two lists of integer is identical:

```
function same_list(l1, l2: list of integer): boolean;
begin
   if (l1 = l2)
      then same_list := true
   else
      same_list := false;
end;
```

continued on next page

Example 2.3 (continued)

We will get the error message:

```
type mismatch in application of the
operator EQUAL
```

This can be resolved by casting the variables **l1** and **l2** into **ob**s before applying the **equal** operator:

```
function same_list(l1, l2: list of integer): boolean;
begin
  if ((l1 as_type ob) = (l2 as_type ob))
    then same_list := true
  else
    same_list := false;
end;
```

The same function can be written as

```
function same_list(l1, l2: list of integer): boolean;
begin
  same_list := ((l1 as_type ob) = (l2 as_type ob));
end;
```

Test cases:

```
SIL>  same_list(list(1,2,3,4), list(1,2,3,4));
TRUE

SIL>  same_list(list(1,2,3,4), list(1,2,3,4,5));
FALSE
```

We can create an even more general version of this function by using **ob**s as input arguments:

```
function same_list(l1, l2: list of ob): boolean;
begin
  same_list := ((l1 as_type ob) = (l2 as_type ob));
end;
```

Test cases:

```
SIL>  same_list(list(1 as_type ob, 2 as_type ob),
                list(1 as_type ob, 2 as_type ob));
TRUE
```

continued on next page

Example 2.3 (continued)

```
SIL>  same_list(list('a' as_type ob, 'Good Morning' as_type ob),
                list(1 as_type ob, 2 as_type ob));
FALSE

SIL>  same_list(list('a' as_type ob, 'Good Morning' as_type ob),
                list('a' as_type ob, 'Good Morning' as_type ob));
TRUE

SIL>  same_list(list('a' as_type ob, mk_point(10.,20.,30.) as_type
                     ob),
                list('a' as_type ob, mk_point(10.,20.,30.)
                     as_type ob));
TRUE
```

universals

All SIL data tagged by type is type **universal**. As with **lispob**, any SIL expression can be cast to **universal** and back. A **universal** is a type tagged **lispob** implemented as a SIL type:

```
type universal = lrecord
    value_of: lispob;
    type_of: ntype;
    end;;
```

Like any other records, **universal**s can be constructed either by using the automatically-defined constructor: **mk_universal** or by using **as_type**. **universal** is most useful if you need to figure out the type of a SIL data object, as illustrated in Example 2.4.

Example 2.4

Checking types of SIL variables:

```
SIL>  type_of(2 as_type universal);
INTEGER

SIL>  type_of('Good Morning' as_type universal);
S_T_R
```

continued on next page

Example 2.4 (continued)

```
SIL>  type_of(pi as_type universal);
RANGLE

SIL>  type_of(mk_point(10.,20.,30.) as_type universal);
POINT

SIL>  type_of(pose('teacher') as_type universal);
FRAME

SIL>  type_of(wlkup('teacher') as_type universal);
SHAPE
```

Example 2.5 shows how to store and retrieve data of different types using **universal**s.

Example 2.5

A common requirement for a tooling database is to store tool offsets (length, radius, etc.) with a tool library. The format of this data, however, may vary with the type of machine-tool (lathe versus machining center) and with the controller used. We can store and retrieve this data using the same SIL type definition by using **universal**.

The SIL declaration for the class **tool_lib** (tool library) is as follows:

```
new_class(tool_lib,
   superclass: generalize: shape,
   changer: tool_changer,
   aux: universal);
```

The class **tool_lib** is a subclass of **shape**, which describes the geometry of the tool library in a workcell. The field changer (of type **tool_changer**) contains data for the tool changer associated with the tool library, and the **aux** (auxiliary field, of type **universal**) contains the tooling data.

NOTE A more detailed description of classes will be described in “Classes and Inheritance” on page 2-24. See Chapter 4, “Geometry in Soft Machines” for **shape** and geometry.

continued on next page

Example 2.5 (continued)

The **aux** field gives us the flexibility of attaching tooling data of different formats to the tool library. For example, the tooling data for a vertical machining center "vmc" is contained in an array of type **vmc_tdata**. We can retrieve the tooling data from the variable **vmc_tlib** (type **tool_lib**) as follows:

```
var atod: darray of vmc_tdata;;
if (type_of(vmc_tlib.aux) = type_of(atod)) then
   atod := vmc_tlib.aux as_type darray of vmc_tdata
else
   writeln('Tool lib contains the wrong data type');
```

Note that we can first validate that the field **vmc_tlib.aux** contains the correct data type before we cast the tooling data from **universal** to **vmc_tdata**.

Applying Procedures

To write a dispatch procedure using **universal**s, we need to use the **apply** operator to apply the appropriate assemble procedure.

function apply(op: id; arg1, arg2, … :): universal

where **op** is the name of an operator, and **arg1, arg2**, … are the arguments to **op**.

```
APPLY: type = FUNCTION(LISPOB,LISPOB,LISPOB) from file:
<NULL S_T_R> protection: 0
APPLY: type = FUNCTION(LISPOB,LISPOB,LIST(LISPOB)) from
file: <NULL S_T_R> protection: 0
type = FUNCTION(AN_IFORM,ID,LIST(IFORM)) from file: <NULL
S_T_R> protection: 0
APPLY: type = FUNCTION(LISPOB,ID,LIST(LISPOB)) from file:
<NULL S_T_R> protection: 0
type = FUNCTION(LISPOB,SCONST,LIST(LISPOB)) from file:
~/cim/builds/nevent51/s/e5_4ap.sil protection: 0
type = FUNCTION(UNIVERSAL,ID,LIST(UNIVERSAL)) from file:
~/cim/builds/danal194/s/a_6univ2.sil protection: 0
type = FUNCTION(UNIVERSAL,APPLICATION,LISPOB) from file:
~/cim/builds/danal194/s/a2_2app.sil protection: 0
```

The **apply** operator provides what is called **late binding**. Late binding means that the decision as to which variant of a function is designated by a function name is made at the latest possible moment: when the function application is actually being executed. Ordinary function application in SIL is of the **early binding** style: the selection of variant is made at the earliest possible time—when the code is read in.

We are now ready to write **dispatch**:

```
procedure dispatch(part: universal);
    begin
    apply("assemble, part)
    end
```

A call to dispatch would look like

```
dispatch(part as_type universal);
```

The **applyn** operator works in a similar fashion, but it returns a failure indicator when no variant is found. The function **is_fail** determines whether or not a **universal** value indicates failure.

Applications

Applications are entities that remember a function and a list of arguments. They are similar to closures, with the added feature of an argument list that can be stored and passed to the function when the application is executed. This function constructs an application:

```
function mk_application(fn : id; args : list of universal) :
                                    application;
```

An application contains the identification (**id**) of a function and the arguments to be passed to it when executed.

This function executes an application:

```
function execute(app: application):universal;
```

The application function is called with the included arguments.

C Data Types

This section contains these topics:

- *C Records and C Arrays*
- *C Strings*
- *C Constants at Build Time*

C Records and C Arrays

Any SIL record or **lrecord** includes a tag word at the beginning for use by the garbage collector. Any SIL array or string has such a tag word too, as well as a length field. The **crecord** facility in SIL allows records and arrays to be declared without including these additional tag words and length fields. The main motivation for this is to allow direct manipulation by SIL code of any C data structure.

The syntax of a **crecord** declaration is just like that of a record or **lrecord**:

```
type erb = crecord
xc: integer;
yc: real;
end;;
```

This is identical in effect to the C declaration:

```
struct erb {  int xc;   double yc;  };
```

then

```
new(erb);
```

returns a value of type

```
^erb
```

i.e., pointer to **erb**, which is equivalent to the C type ***erb**.

The usual SIL syntax can be used to select and set the fields of an **erb**:

```
ee == new(erb); ee . xc := 56; ee .yc := 5.4 + ee . xc;
```

Similarly, a **carray** is an array without tag or length fields. A **carray** can be created with

```
cc == carray_create(integer,10);
```

The "**^**" syntax can be used to make a pointer, as in

```
aa == ^(ee . xc);
```

or

```
aa == ^cc[4];
```

The type of **aa** is **^integer**. The only legal arguments to **^** are fields of **crecord**s and entries in **carray**s. Pointers are de-referenced as follows:

```
aa^;
```

then

```
aa^ := aa^ + aa^;
```

will double the integer value pointed to by **aa**.

crecords and **carray**s can be built from the primitive types **cchar**, **cshort**, **integer**, **real**, **sreal** or from other **crecord**s or **carray**s.

SIL Type	Identical to C Type
cchar	**char**
cshort	**short**
sreal	**float** (single precision real)
integer	**int**
real	**double**

The types **cchar**, **cshort**, and **sreal** should appear only as the subtypes of **carray**s, pointers, or **crecord**s.

Alignment is done as in C—each type is aligned to an even multiple of its length.

cchars and **cshorts** when extracted turn into SIL integers, and **sreals** into SIL reals.

C Strings

There are a couple of utilities for going back and forth between SIL **lstring**s and C strings.

The type **cstring** is defined just to be a synonym for **carray_of(cchar)**. The following operations are provided:

```
function to_cstring(x: lstring): cstring;
```

This first checks that the contents string of **x** is **static** (does not get moved around by the garbage collector) and null-terminated. If either of these conditions is violated, a new contents which is tenured and null-terminated is generated and set up as the contents part of **x**. The **cstring** returned is a pointer to the "raw" (untagged) contents of **x**. So, the **cstring** will occupy the same storage as the contents of **x**, and will be null-terminated. Since the storage for the resulting **cstring** cannot be freed, this function should be used only to create permanent **cstring**s.

The following function statically allocates a brand-new null-terminated **cstring** with capacity equal to that of **x**, and copies **x** into it. Since the storage for the resulting **cstring** cannot be freed, this function should be used only to create permanent **cstring**s.

```
function mk_cstring(x: lstring): cstring;
```

REMINDER The capacity of an **lstring** is usually bigger than its current length.

The following function dynamically allocates a brand-new null-terminated **cstring** with capacity equal to that of **x**, and copies **x** into it. The storage for the resulting **cstring** can be freed with **free_cstring**.

```
function new_cstring(x: lstring); cstring;
```

This procedure frees the **x cstring**, which has been created dynamically by **new_cstring**:

```
procedure free_cstring(x: cstring);
```

This procedure copies **c** to **x**, stopping at a null in **c**, or the capacity of **x**, whichever comes first:

```
procedure copyto(x: lstring;c: cstring);
```

The following procedure copies **x** into **c**. Since **c** has no length indication, this can be dangerous—if **c** was allocated to be shorter than the current length of **x**, then the memory after **c**'s length allocation will be deleted.

```
procedure copyto(c: cstring;x: lstring);
```

The print function for **cstring**s will print characters until a null is hit, or the limit **max_cstring_print_length** is reached.
max_cstring_print_length is initially 100.

If you want to allocate an **lstring** to be passed to C, you may wish to use

```
function mk_static_lstring(x: string;n: integer): lstring;
or
function mk_static_lstring(x: string): lstring;
```

Either of the above functions are used to construct **lstring**s that are already static and null terminated.

This procedure will cause the contents of **x** to become static and null terminated (if they are not already):

```
procedure mk_static(x: lstring);
```

C Constants at Build Time

> **NOTE** "Builds" are described in Chapter 3, "Working with SIL Code".

C data structures can only be safely created at build time by using the construct

```
cstring_constant(aa,'abc');
```

This has exactly the same effect as

```
aa == mk_cstring('abc');
```

except that **cstring_constant** records the need to reset **aa** when a state starts up, making it safe for use in compiled code.

Casting

In SIL, an expression's type can be modified by the **as_type** operator. The effect of this operator is analogous to that of the C cast primitive—it asserts that the value of the expression should be treated as belonging to a specified type, whatever the type originally assigned to the expression may have been. The syntax is

```
<expression> as_type <type>
```

Example 2.6

SIL> **var d1, d2: dangle;; { "dangle" is angle in deg }**

The SIL expression

SIL> **d1 := 30.;**

will give the following error message:

```
error: COULD NOT COERCE REAL TO DANGLE IN 30.00000
```

This is because SIL regards **dangle** and **real** as distinct data types.

continued on next page

Example 2.6 (continued)

A solution would be to cast **30.** to type **dangle** with the following expressions:

```
SIL>  d1 := 30. as_type dangle;
```

To continue with our example:

```
SIL>  d2 := d1 + pi/4.;
SIL>  var r1: real;;
SIL>  r1 := d2 as_type real;
SIL>  r1;
75.0000000
```

Not all **as_types** are legal. The rule (which has a few exceptions given later) is that the data format of the value to be cast must agree with the data format of the type to which it is being cast. Another restriction is that a record cannot be cast to an **lrecord**, nor an **lrecord** to a record.

SIL Constants

All SIL definitions have internal representations called **sconst**s (SIL constants). An **sconst** is like a descriptor which contains type, name, and value fields for the defined object.

Because SIL is a polymorphic language, a single id **x** can be the name of several **sconst**s. However, only one of these **sconst**s can represent a non-function type. This **sconst** is the *data* variant of **x**; the other **sconst**s are the *function* variants of **x**. The following operators help locate an **sconst** using an **id**:

```
function data_variant(x:id): sconst;
function has_data_variant(x:id): boolean;
function function_variants(x:id): list of sconst;
function has_function_variant(x:id): boolean;
```

Because two function variants with the same name must have distinct input types, a name and a list of input types uniquely specify an **sconst** for a function variant. We can fetch this **sconst** with

```
function find_variant(x: id; intps: list of ntype): sconst;
```

More generally, an **id** and a type specify an **sconst** which can be fetched by

```
function find_variant(x: id; tp: ntype): sconst;
```

If there is no variant of the indicated type, a special **sconst**, **undefined_sconst** is returned. To test for **undefined_sconst**:

```
function is_undefined(x: sconst): boolean;
```

This function applies the given **sconst** to the given arguments.

```
apply(op: sconst; a: list of lispob);
```

Polymorphism

A **polymorphic** typing system is one which permits one name to name several objects at the same time *as long as these objects have different types*. For example, the function **sin** accepts both **rangle** and **real** type inputs. In SIL, a name can have at most one data variant but any number of function variants. Each function variant, however, must have distinct input types (for instance, **moveto** in SIL has over 20 variants).

Consequently, in Example 2.7, these two variants of **same_list** can coexist at the same time.

Example 2.7

```
function same_list(l1, l2: list of integer): boolean;
function same_list(l1, l2: list of ob): boolean;
```

Classes and Inheritance

This section contains these topics:

- *Classes*
- *Inheritance*
- *Specialization and Generalization* (how objects are viewed relative to each other, and how to manipulate the views)
- *Abstract Classes*

One of the main characteristics of object-oriented programming is the concept of **inheritance**. Two objects, **A** and **B**, belonging to different types (classes), can be related in such a way that all properties of **A** are also properties of **B**. In this case, **B** inherits **A**'s properties. In SIL terminology, **B** is a **specialization** of **A**, since **B** may have additional "specialized" properties apart from those inherited from **A**; or **A** is a **generalization** of **B**. Applying this concept to machine-tools, we can say that a machining center is a specialization of an NC machine, which in turn is a specialization of a kinematics device.

The advantage of inheritance is that programmers do not have to build an object from the ground up. By declaring object **B** to be a specialization of **A**, the properties of **A** automatically become properties of **B**. This is especially useful if **A** is a system-defined object with many useful, but low-level, properties. For example, **B** might be a cutting-tool with properties such as location of cutting tip, cutting edge, etc., whereas **A** might be a CAD model with geometric and graphical properties such as boundary representation, surface normals, color, etc. If you are creating a simulation of an NC machining process, you are probably familiar with the cutting properties of a cutting-tool, but may not be familiar with the lower level properties of a CAD model, even though these properties are necessary for displaying and manipulating the cutting-tool in a simulation. Because Soft Machines provides a type (class) **shape**, which represents a simulated object in three-dimensional space, the class **cutting_tool** (cutting tool) can simply be described as a specialization of **shape**.

Classes

The definition of a class in SIL is very similar to a Pascal (or SIL) record definition:

```
type <new_class> = class
   superclass:<class1>;
   superclass:<class2>;

   …
   <instance-var-1>:<type1>;
   <instance-var-2>:<type2>;

   …
   end;;
```

Example 2.8 illustrates how to define a subclass for a cutting tool.

Example 2.8

```
new_class(cutting_tool,
   superclass: generalize: shape,
   flange: frame,              { Mount flange }
   tip: frame,                 { Cutting tip }
   cutter_type: id,            { Cutter characteristics }
   diam: real,
   length: real,
   cutting_angle: rangle,
   flute_length: real);;
```

To model a cutting tool, follow this sequence:

1. Construct a Soft Machines model using the CAD Interfaces panel or the **Modeling** pulldown menu.
2. Teach flange and cutter tip on model.
3. Declare other cutter characteristics.
4. Construct cutting tool using

```
mk_cutting_tool(wlkup(<model_name>), cutter_flange,
                cutter_tip, .... );
```

Inheritance

Class inheritance is used extensively throughout Soft Machines. As mentioned earlier, a machining center is a specialization of an NC machine, which is a specialization of a robot. Thus, the class **nc_machine** inherits all the properties of the class **robot**, such as forward and inverse kinematics, joint limits, velocity and acceleration, etc. In other words, all functions using **robot** as input type can also be used for **nc_machine**, without explicit casting to type **robot**.

Example 2.9 introduces the principles of inheritance. In this example, robot-related functions are used for NC machines.

Example 2.9

Suppose the variable **vmc** is of type **nc_machine**, a subclass of **robot**. We can use robot-related functions on **vmc**, such as

Current joint vector of **vmc**:

```
c_jv(vmc);
```

Move axes (links) of **vmc**:

```
moveto(vmc, c_jv(vmc)+mk_jv(10.,20.,0.,0.,0.,0.));
```

Move one link (Link 1) by 10cm.

```
moveby(wlkup(vmc), 1, 10.);
```

Specialization and Generalization

The specialize_to Operator

Figure 2-3 shows a simplified class hierarchy of objects in Soft Machines. All geometric entities in a Soft Machines workcell are represented as type **shape**.

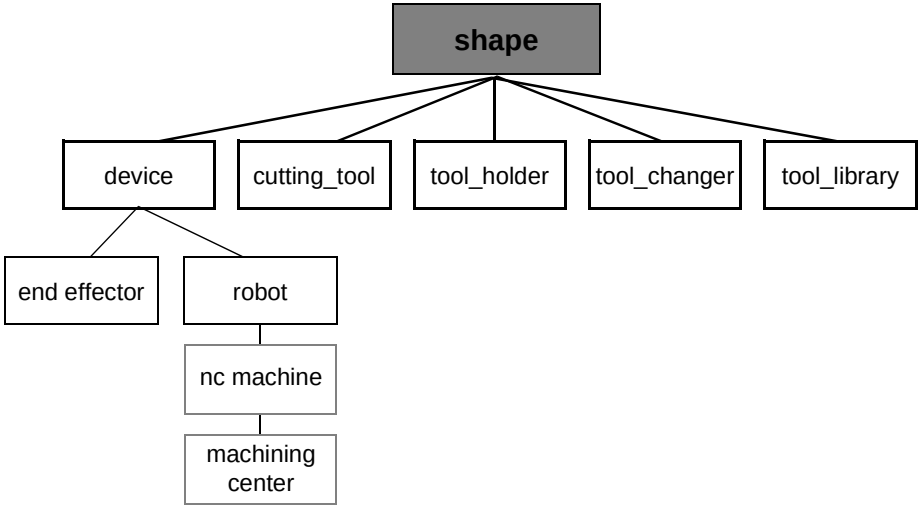


Figure 2-3 Object class hierarchy

The **specialize_to** operator is used to access subclasses of any Soft Machines object. Conversely, to access the superclass of an object, **generalize** is used. When an object is first installed into a workcell (as type **shape**), we use **specialize_to** to retrieve the subclass. We can also determine whether a shape contains the valid subclass by checking whether **specialize_to** returns a **nul**.

Example 2.10

Install cutting tool from file:

```
var   sh: shape;
      ct: cutting_tool;;
sh := install(<shape_name>, <file_name>);
ct := specialize_to(sh, cutting_tool);
```

Example 2.10 (continued)

Check whether a shape contains an NC machine:

```
function is_nc_machine(sh: shape): boolean;
begin
   if object_exists(name(sh)) then
      is_nc_machine :=
         not(nul(specialize_to(sh, nc_machine)))
   else
      is_nc_machine := false;
end;
```

Views

Two objects are **referentially equivalent** if they are both views of the same entity. Clearly, if object **A** generalizes object **B**, then **A** and **B** are referentially equivalent. But two objects can be referentially equivalent *without* one generalizing the other.

The list of all views referentially equivalent to an object is given by the function **views**. The **views** function returns a list of **universal**s (objects, like any other SIL data, can be cast to and from **universal**s). The list of classes to which these views belong is given by the function **classes**. This is a list of **ntype**s. The class of an object is given by the function **my_class**.

Because referentially equivalent objects represent the same entity, we would like all views of **A** (i.e., not just the specializations of **A**), to be able to use the methods and attributes of **A**. Doing this requires changing views using the **as_view** or **to_view** infix operator:

```
<object> as_view <class>
<object> to_view <class>
```

When **<object>** has no view in **<class>**, **<object> as_view <class>** generates an error message while **<object> to_view <class>** returns a null object which can be tested for using the **nul** predicate.

Two simple operators are provided for directly manipulating the views of an object: **splice** and **remove_this_view**.

The **splice** operator simply appends the views of **object1** onto those of **object2**. So, **object1** and **object2** are unified—they become referentially equivalent. **object1** may not be spliced onto **object2** if any view of **object1** has the same class as a view of **object2**.

The **splice** operator works like this:

splice(<object1>,<object2>);

The **remove_this_view** operator works like this:

remove_this_view(<object>);

The **remove_this_view** operator will generate an error if the class of any other view of the object is a subclass of the class of the view being removed. If this restriction were not observed, objects with dangling superclass pointers would result.

A view which has been removed should not be referenced after its removal.

Abstract Classes

This section describes the abstract class facility and is intended for advanced SIL language users. This section includes the following topics:

- Installation of Methods
- Additional Methods Primitives
- The mnode Class

The abstract class facility provides the same sort of functionality as C++ virtual functions—you can define abstract classes whose methods can be implemented by a variety of concrete classes. The facility is more flexible than anything available in C++ in that it allows dynamic modification of the implementing classes and methods of an abstract class. Abstract classes can also be spliced onto pre-existing concrete classes, allowing abstractions to be layered onto existing bodies of concrete code.

Example 2.11 introduces abstract classes by showing a conventional example—an "abstract stack" class.

Example 2.11

```
type astack = class
  push: method(ob,ob);
  ipop: method(ob);
  empty: method(boolean);
  on_underflow: method(ob);
  end;;
```

NOTE This example will be continued after the following information.

The method fields are slots which hold operators on **astack**, just as ordinary fields of a class hold data. The usage

method(<return-type>,<input_type$_1$>,… <input_type$_n$>)

specifies a "method" which can be applied to inputs of types **astack**, **<input_type$_1$> ...<input_type$_n$>**, and will return the given return type. So, for example, **push** takes an **astack** and an **ob**, and returns an **ob**. The first argument to any method is the class for which the method is defined, so it need not be specified explicitly. It is for this reason that we write **method(ob,ob)** rather than the redundant **method(ob,astack,ob)**.

Now, the method slots in a class definition are filled by ordinary SIL functions which take a view of the **astack** as first argument. For example, the operator installed in the **push** slot will be a procedure which takes a view of an **astack** as its first argument, and an **ob** as its second. The intent of this should become clear as we proceed with this example.

Example 2.11 (continued from above)

Now, we define the concrete class **lstack**:

```
type lstack = class
    superclass:astack;
    goods:list of ob;
    end;;
```

Example 2.11 (continued from above)

Here are some of its methods:

```
procedure push(x:lstack;y:ob);
    begin
        x . goods := cons(y,x . goods);
    end;

function pop(x:lstack):ob;
    begin
        if null(goods(x)) then pop := nil else
        begin
            pop := car(goods(x));
            x .goods := cdr(goods(x));
        end;
    end;

function empty(x:lstack):boolean;
    begin
        empty := null(goods(x));
    end;
```


Installation of Methods

Installation of methods is done using the following primitives. If **a** is a particular **astack**, which is also an **lstack**, we can set the method **push** in **a** to be **push** on the **lstack**. The following does this:

```
a == mk_astack();
l == mk_lstack(a,emptylist(ob));
set_method(a,"push,"push,list(lstack,ob));
```

That is, when **push** is called on **a,** it "delegates" the work to the **push** variant on **lstack**. So,

```
push(a,x);
```

is equivalent in effect to

```
push(a as_view lstack,x);
```

Example 2.12

```
a == mk_astack();
l == mk_lstack(a,emptylist(ob));

set_method(a,"push,"push,list(lstack,ob));

function pop(x:astack):ob;
      begin
      if empty(x) then
          begin
               if method_defined(x,"on_underflow) then
                    on_underflow(x);
               pop := nil;
          end
      else
          pop := ipop(x);
      end;
```

As illustrated above, the operator

method_defined(x:<any type>;y:id);

determines whether the given method has been installed in **x**.

The following operator makes an **astack** with the **lstack** implementation:

```
function mk_lstack(): astack;
     var a: astack; l: lstack;
     begin
          a := mk_astack();
          l := mk_lstack(a,emptylist(ob));
          set_method(a,"push,"push,list(lstack,ob));
          set_method(a,"ipop,"pop,list(lstack));
          set_method(a,"empty,"empty,list(lstack));
          mk_lstack := a;
     end;
```

Note that no method is assigned to **on_underflow**. A user of **astack** is free at any time to execute a **set_method** to install a method for underflow.

Additional Methods Primitives

The following are more primitives for methods.

```
pmethods(x:<any_type>);
```

prints out the methods currently installed in **x**. This is useful for debugging.

```
define_method(astack,lstack,"ipop,"pop);
```

Instead of installing a method into any particular **astack**, the above use of **define_method** defines a standard method to use for **ipop** for any object that is an **astack** implemented by an **lstack**. For **astack a**

```
use_methods(a,lstack);
```

installs all of the standard methods for **astack** associated with **lstack** into **a**.

The **pop** method does not get installed by **define_methods** because **ipop** is the abstract method name, while **pop** is the implementation name.

Rule 2.1
To remember the argument order for the above primitives, an easy rule is **Abstract information always precedes the concrete information in the argument order.**

Methods can be declared to be tasks rather than procedures by using the keyword **tmethod** rather than **method**.

The mnode Class

mnode is an abstract class, and is the class of all screen items (widgets). The word **mnode** comes from “node in the menu tree.” Actual widgets are built by subclassing and/or splicing an **mnode**.

Concurrency

This section explains how to use SIL for concurrent execution of multiple tasks within one “state” or data space. This section contains these topics:

- *Tasks*
- *Tickers*
- *Semaphores*
- *Pipes*
- *Processes*

SIL maintains a global variable called **clock** which measures the passing of simulated time. Certain SIL commands cause **clock** to be advanced when they are called. Commands that consume simulated time are called **temporal**. Non-temporal commands are called **instantaneous**. A block of instantaneous commands is called an **instantaneous block**.

Temporal commands are used in simulations that model time. These commands include those that move or operate kinematics devices such as robots, NC machines, and automatic tool changers.

Do not confuse simulated time with real time. An infinite loop will consume an indefinite amount of real time, but may consume no simulated time if it contains only instantaneous commands. Simulated time is also independent of the computer hardware used or system load, and is determined by the task scheduler based on the kinematics characteristics (distance moved, velocity, acceleration, etc.) of the simulated object. A simulation running on a faster computer may consume less real time, but the simulated time should be identical if the same simulation is run on a slower computer.

Tasks

All SIL function and procedure calls are instantaneous. **No temporal commands can be called in the body of a function of procedure**. Temporal commands are created by defining **tasks**. The syntax for defining a task is similar to that for defining functions and procedures (see Example 2.13).

Example 2.13

```
task ncv_moveby(sh: shape; link: integer; dist: real);
var jk: joint_kinds;
begin
   jk := revolute(sh);
   if jk[link] then
        moveby(sh, link, dist)
   else
       moveby(sh, link, dist*current_unit);
end;

{ M03 Spindle Clockwise }
task m3(nc: nc_machine; g: gcode_info): gcode_status;
var msg: string;
begin
   nc.status.spindle := 'cw';
   spindle_on(nc);
   msg := concat('active_nc_machine.status.spindle :=
                      '','cw',''';');
   m3 := mk_gcode_status(true, g.stmt_no, msg);
end;
```

Calling any temporal command from inside of a task (for instance, calling **moveby** from inside **ncv_moveby**, or calling **spindle_on** from task **m3**) will cause the task to consume simulated time. In fact, a task can be thought of as a sequence of instantaneous commands separated by calls to temporal commands.

Delay

The simplest way to consume simulated time from inside of a task is to call the most primitive temporal command:

delay(<seconds>)

When called from inside of a task, **delay** will cause the task to suspend itself until an indicated number of seconds have advanced. Suspended tasks are also called **sleeping** or **delayed** tasks. Example 2.14 illustrates how to call **delay** from within tasks.

Example 2.14

```
{ Index turret by angular increment }
task index_turret(m: nc_machine; tur_incr: real);
begin
{  Unaffix tool lib from mount, rotate by angular increment,
   pause for ncv_tool_change_interval }
   unaffix(m.tlib, m.changer_mount);
   moveto(m.tlib,
                        mk_ypr(0., 0., tur_incr) rel pose(m.tlib));
   affix(m.tlib, m.changer_mount);
   delay(ncv_tool_change_interval);
end;
```

Start and Run

Although a single task can be executed by calling it in the same manner as a function or procedure, it will not work when executing many tasks concurrently. To do this, you need to first place the tasks to be executed in the run queue by using the **start** command:

start("<task> [, <arg>, …, <arg>]);

where **<arg>, …, <arg>** are optional arguments to **<task>**.

NOTE

The behavior of tasks run differs slightly depending on if you are programming in Menu Mode or in Text Mode. In Menu Mode, the Scheduler is active whenever tasks have been started or called. In Text Mode, the Scheduler is activated only by explicitly calling a task or executing the following command:

run();

The **start** command may be used at the top level or within a task. Use the **run** command only at the top level.

Example 2.15

In this example, the type **ncv_sync_block** contains data for synchronized machining (multiple turret lathes), and the task **do_nc_tasks** executes the data specified in each **ncv_sync_block**. Simultaneous machining is simulated by placing a list of **do_nc_tasks** in the run queue and then processing them concurrently with the **run** command.

```
procedure do_simul_tasks(losb: list of ncv_sync_block);
var j: integer;
begin
   for j := 0 to length(losb)-1 do
   begin
      start("do_nc_tasks, losb[j]);
      if (do_material_removal and time_slice_mode) then
         start("do_material_removal, losb[j].nc);
   end;
   run();
end;
```

Tickers

Tickers are instantaneous commands that run at regular intervals during a simulation. Care must be taken when writing a ticker—if it is computationally intensive, or runs too often, the simulation may slow considerably.

Tickers are useful for gathering data during a simulation, and for applying rules and laws to the simulated environment.

This function constructs a ticker which runs an application at the given interval of the simulation clock:

function mk_ticker(app : application; intv : real):ticker;

where **app** is an application to run, and **intv** is the time interval at which to run.

NOTE Applications are described in "Applications" on page 9-11.

These procedures start and stop a ticker:

```
procedure activate(tck : ticker);
procedure deactivate(tck : ticker);
```

Semaphores

The basic synchronization mechanism in SIL is the **semaphore**. Other methods of synchronization, such as pipes and process lines, are available, but they all depend on semaphores. **semaphore** is a SIL type, with the following operations:

```
wait(<semaphore>);

signal(<semaphore>);

value(<semaphore>): integer;

new_semaphore(): semaphore;
```

A semaphore **s** with value **n** may be thought of as representing **n** units of some resource. The **wait(s)** operation, when executed by a task, is a request for one unit of the resource. If the value of the semaphore is greater than 0, then the value is simply reduced by 1, and the wait returns. If, however, the value is 0 when **wait(s)** is executed, the task which executes the wait is suspended until some other task makes a unit of the resource available. If other tasks are already waiting for the resource (that is, have executed **wait(s)**), then our task is added to the end of a queue associated with the semaphore.

The command **signal(s)** adds a unit of resource to the semaphore. If there is a queue of tasks waiting for the resource, the first element of the queue is resumed. If no tasks are waiting, the value of the semaphore is incremented.

Example 2.16

Suppose the tool change sequence of a machining center includes the following operations:

1. Search for cutting tool from tool magazine.
2. Swap tool between spindle and tool magazine.
3. Start machining, search for next tool at the same time.

The machine checks whether to tool search operation has completed before initiating the swap tool sequence, i.e., swap tool waits until search tool is ready.

We use the semaphore **searching_tool** to represent the availability of cutting tool:

```
searching_tool == new_semaphore();
```

Initially, the tool magazine is ready:

```
signal(got_tool);
```

The task **swap_tool** waits until tool magazine is ready, then swap cutting tool between spindle and tool magazine. When done, it signals that machine is ready for the next tool search.

```
task swap_tool(m: nc_machine);
begin
   wait(got_tool);
   do_swap_tool(m);
   delay(ncv_tool_change_interval);
   signal(got_tool);
end;
```

Task **index_tc** positions the tool magazine to the correct station once tool changer is ready, and task **search_tool** puts **index_tc** in the run queue, so that tool search executes concurrently with other machining operations.

Example 2.16 (continued)

```
task index_tc(m: nc_machine; stn_no: integer);
begin
   wait(got_tool);
   ncv_index_tc(m, stn_no);
   signal(got_tool);
end;

task search_tool(m: nc_machine; tool_no: integer): boolean;
var stn_no: integer;
begin
   stn_no := find_tool_station(m, tool_no);
   if (stn_no > 0) then
      begin
         search_tool := true;
         start("index_tc, stn_no);
      end
   else
      search_tool := false;
end;
```

Pipes

Pipes are used for communication between tasks. A pipe of type **pipe(<type>)** is a structure of the form:

```
pipe =lrecord
     messages: queue of <type>;
     waiters: queue of tasks
     end;
```

Tasks can either place messages at the end of the **messages** queue of a pipe, or remove messages from the front of the **messages** queue. If a task tries to remove a message when the **messages** queue is empty, then the task suspends itself on the **waiters** queue of the pipe until a message arrives. Note that **messages** does not have specific tasks as destinations.

To create a pipe of type **<type>**, we use the **new_pipe** command:

```
p == new_pipe(<type>);
```

To place a message **<msg>** of type **<type>** in **p**, we use **signal**:

signal(<msg>, p)

If the **waiters** queue is empty, then **signal** simply adds **<msg>** to the **messages** queue of **p**. If the **waiters** queue is not empty, the **messages** queue will be empty, and **signal** wakes up the first task on the **waiters** queue and personally delivers **<msg>**.

The **wait** command returns the next message in a pipe, if there is one. Otherwise, it will suspend the current task and add it to the **waiters** queue. Both **wait** and **signal** are temporal commands that return control to the scheduler when they complete.

Processes

When a task places a message in a pipe there is no guarantee as to which task will receive this message, since any task can extract messages from any pipe. Alternatively, a task can have private pipes. While any task can place a message in a private pipe, only the owner task can extract messages from the pipe.

Processes are parameterless tasks that do not return values. The syntax for defining a process is a little different from the syntax used for defining tasks:

```
process <name>([<private pipes>]);
    [<local variable declarations>]
    <task body>;
```

where

<private pipe> ::= <pipe name>[, <pipe name>, …, <pipe name>]: <type>

and

<private pipes> ::= <private pipe>, …, <private pipe>

The key word **process** alerts the task-defining machine that the parameters are to be interpreted as private pipes rather than parameters.

SIL provides a variant of **signal** for sending a message **<msg>** to a private pipe **<ppipe>** owned by process **<proc>**:

signal(<proc>, <ppipe>, <msg>)

SIL also provides a variant of **wait** for removing messages from a private pipe. The command

wait(x)

causes the current process (i.e., the one calling wait) to suspend itself if the pipe **x** is empty. When a message arrives in **x** the process will resume. If **x** is not empty, then the first value in **x** is assigned to the parameter **x** and can be referenced that way until the next time **wait(x)** is executed. Just as with public pipes, **wait** will return the first value stored in a pipe or suspend itself if the pipe is empty.

Closures and tclosures

This section contains these topics:

- *Closures*
- *tclosures*
- *Using Closures and tclosures to Customize G Code Translators*

Closures

Closures are entities in SIL which allow functions to be manipulated as data to be passed to functions, inserted in data structures, etc. Example 2.17 illustrates this concept.

Example 2.17

In this example, we want to upload part program file (G code data) into Soft Machines by translating G code statements into common SIL data structure of type **gcode_info**. The syntax of the G code data, however, may vary from controller to controller, which means that different G code translators may be required for different controllers.

```
function fanuc_read(fname: string): list of gcode_info;
begin
   { Initialize global variable gc_file }
   gc_file := mk_file(fname);
   open(gc_file, 'input');
   { fn_gcode_read constructs fn_logc, a list of gcode_info
     (G code data structure) }
   fn_gcode_read();
   fanuc_read := fn_logc;
end;

function siemens_read(fname: string): list of gcode_info;
begin
   gc_file := mk_file(fname);
   open(gc_file, 'input');
   siemens_gcode_read();
   siemens_read := fn_logc;
end;
```

Two closures are declared as follows:

```
fanuc_cl ==
mk_closure("fanuc_read, list of gcode_info, string);

siemens_cl ==
mk_closure("siemens_read, list of gcode_info, string);
```

Note that the variables **fanuc_cl** and **siemens_cl** are of type

```
closure(list of gcode_info, string);
```

Example 2.17 (continued)

A general task is declared for NC simulation:

```
task simulate_part_prog (m: nc_machine; fname: string;
                         gcode_translator(list of gcode_info, string));
var logc: list of gcode_info;
begin
   logc := gcode_translator(fname);
   do_nc_task(m, logc);
end;
```

Machines with different controllers can be simulated using the same task:

VMC with FANUC controller:

```
SIL> simulate_part_prog(vmc, 'fanuc_Gcode_file',
                        fanuc_cl);
```

Hermle with SIEMENS controller:

```
SIL> simulate_part_prog(hermle_uwf,
                        'siemens_Gcode_file',
                        simens_cl);
```

Even different controllers running on the same machine can be simulated:

```
SIL> simulate_part_prog(hermle_uwf, 'siemens_Gcode_file',
                        simens_cl);
SIL> simulate_part_prog(hermle_uwf, 'fanuc_Gcode_file',
                        fanuc_cl);
```

Note that the following will not work:

```
SIL> simulate_part_prog(hermle_uwf, 'fanuc_Gcode_file',
                        fanuc_read);
```

because **fanuc_read** is a function, not a data value.

Closures can be manipulated just like any SIL data objects. They can be inserted into SIL data structures, constructed into lists or arrays, and passed as arguments among functions, procedures and tasks.

To continue with the last example (Example 2.17), the G code translator can be attached to a data type, combining the controller with the machine properties. As a matter of fact, Soft Machines utilizes such a concept when creating the class **nc_machine**. The field **nc_machine.translator** is of type **gc_translator**, which is declared as

```
type gc_translator: closure(ob);;
```

The G code translator can easily be incorporated into the **nc_machine** data structure as follows:

```
my_machine.translator :=
mk_closure("my_gcode_reader, function(ob));
```

where **my_machine** is of type **nc_machine**, and **my_gcode_reader** is a procedure with no arguments.

NOTE SIL procedures are considered as functions that return an **ob**.

When declaring a closure of

```
procedure my_procedure(arg1: arg1_type; arg2: arg2_type; ...);
```

the following is used:

```
my_closure :=
mk_closure("my_procedure, function(ob, arg1_type, arg2_type, …);
```

tclosures

A **tclosure** is to a task what a closure is to a function: a passable data item whose value is a task rather than a function.

Example 2.18

In a part program, M code 6 (**M6**) usually means executing a tool change. Since different machines may have vastly different tool change sequences (e.g., turret versus chain-type tool changers), the same code (**M6**) may be calling very different tasks.

The same task closure can represent machine specific tasks such as tool changes:

```
task vmc_m6(nc: nc_machine; g: gcode_info): gcode_status;
begin
   vmc_tool_change(nc, g);
   vmc_m6 := mk_gcode_status(true, 'M6 - vmc_tool_change',
                                          g.stmt_no);
end;

task deckel_m6(nc: nc_machine; g: gcode_info): gcode_status;
begin
   deckel_search_tool(nc, g);
   deckel_swap_tool(nc);
   deckel_m6 := mk_gcode_status(true,
                              'M6 - deckel_tool_change', g.stmt_no);
end;
```

For machine VMC:

```
m6 := mk_closure("vmc_m6, task(gcode_status, nc_machine,
                        gcode_info));
```

For machine DECKEL:

```
m6 := mk_closure("deckel_m6, task(gcode_status, nc_machine,
                        gcode_info));
```

Using Closures and tclosures to Customize G Code Translators

We have seen how we can insert a function (G code reader) into the class **nc_machine** by using **closures**; and represent machine specific tasks using a single **tclosure**. The behavior of a Soft Machines device, such as a robot or an NC machine, can easily be customized through the manipulation of closures.

In a Soft Machines simulation, machines of various designs and configurations can be controlled by the same set of SIL commands (**moveto**, **moveby**, **home**, **...**, etc.), even though the kinematics may be very different. A 2-axis lathe does not move in the same manner as a 3-axis milling machine; a travelling column horizontal machining center with a tilt/rotary table is totally different from a gantry-style milling machine with a nutating head. This is because functions such as forward and inverse kinematics, and the machine's path planner, are inserted into the robot data class as closures.

Similarly, the NC codes **G0** (rapid mode), **G1** (linear motion), **G2** (circular motion), etc., may look the same from the part programmer's port of view, but the motion algorithms used to execute these commands need to be customized for each machine.

This is easily accomplished in Soft Machines by adding two arrays of **tclosure**s to the object class **nc_machine**, one array for G codes, and the other for M codes:

```
type gcode_closure =
            tclosure(gcode_status, nc_machine, gcode_info);;

type g_function = lrecord
      group: integer;
      cl: gcode_closure;
   end;;

new_class(nc_machine,
   superclass, generalize: robot,
      .
      .
   gtable: array_of(g_function),
   mtable: array_of(gcode_closure),
   translator: gc_translator,
      .
      .    );;
```

To insert or change G and M codes of an NC machine, we use the procedures **add_gcode** and **add_mcode**:

```
procedure add_gcode(code, group: integer; task_id: id;
                           table: array_of(g_function));
begin
   table[code] := mk_g_function(group,mk_closure(task_id,
               task(gcode_status, nc_machine, gcode_info)));
end;

procedure add_mcode(code: integer; task_id: id;
                           table: array_of(gcode_closure));
begin
   table[code] := mk_closure(task_id,
               task(gcode_status, nc_machine, gcode_info));
end;
```

To continue with Example 2.18, we can add **M6** to the **nc_machines** "**vmc**" and "**deckle_dz4s**" as follows:

```
add_mcode(6, "vmc_m6, vmc.mtable);
add_mcode(6, "deckel_m6, deckel_dz4s.mtable);
```

To execute the command **m6**:

```
var        m6: g_function;
g_status: gcode_status;;
```

For **VMC**:

```
m6 := vmc.mtable[6];
g_status := m6(vmc, gcode_stmt);
```

For **DECKEL_DZ4S**:

```
m6 := deckel_dz4s.mtable[6];
g_status := m6(deckel_dz4s, gcode_stmt);
```

Symbols

A **symbol** is a name. Constants, variables, type names, and function/procedure names are examples of symbols.

SIL features symbols that not only *name* data objects (**lispob**s), but are data objects themselves. In this way, a symbol can be passed to a function/procedure as a parameter, returned from a function as a value, or can be named by another symbol (which might be a variable or a constant).

The SIL data type of all symbols is called **id** (which is short for **ID**entifier). Of course, SIL expressions must distinguish between use and mention of an **id**. To make this distinction, precede all mentions of an **id** with double quotes (**"**).

Chapter 3

Working with SIL Code

This chapter explains how to load, compile, and debug code and how your SIL code is protected.

Protection

In order to keep users from overwriting system code, each SIL entity (global, function, task, etc.) is assigned an integer protection level. The following global:

current_authorization

controls the protections assigned to SIL entities. Any attempt to redefine an entity with protection level greater than that defined by **current_authorization** will result in an error. Resetting the value of an existing global with the symbol

:=

does not require any authorization; however, resetting this type and value with this symbol

==

does require adequate authorization. System functions generally use a 0 as their protection level. The default value of **current_authorization** is -1. You can set authorizations to the level you wish by using

current_authorization := <level>;

Input/Output

This section includes the following topics:

- *Reading from the Keyboard*
- *Writing to the Screen*
- *Reading and Writing to a File*
- *EOF*

Presenting **SIL I/O** capabilities consists mainly of listing conventions which, because of their simplicity, need no explanation. For this reason, this section contains a series of annotated examples. These examples will serve to demonstrate how to use the I/O conventions, and in what context.

Reading from the Keyboard

Example 3.1

Assume that the following declarations are made:

```
var a:integer; b:string;;
```

The **read** command instructs the interpreter to assign the next value it reads to the variable argument of the read procedure (=> indicates input by the user in absence of prompt):

```
SIL>  read(a);
=>  37
SIL>  a;
37
```

More specifically, **read(x)** causes the next token in the input stream to be read in. The type of **x** must be string, integer, real, id, or **lispob**. If the token can be interpreted as a data item of the kind indicated by the type of **x**, then **x** will be assigned this value; otherwise, an error will occur. Any token can be interpreted as a string or **lispob**. The obvious

restrictions apply to integers and reals. IDs must follow the SIL rules for IDs (alphabetic character followed by a sequence of non-delimiters). Reading a token as a **lispob** and a string may yield different results.

Example 3.2

```
var aa :string;;
SIL>  read(aa);
 =>123
```

results in **aa** being assigned the string 123.

```
SIL>  aa == nil;
SIL>  read(aa);
 => 123
```

results in **aa** being assigned the integer 123 cast as a **lispob**. (see "lispobs" on page 7-4 for more information).

Finally, we note that a quoted string as in

```
'hello there'
```

is read as a single string-valued token.

The **readln** command reads one token from the input, and then discards the rest of the line (if any) on which the token appears.

In addition to the **read** and **readln** procedures, the following functions are available:

- **read_char()** reads just one character, and returns its ASCII code.
- **read_token()** reads one token, and returns it as a **lispob**.
- **read_line()** reads an entire line, and returns it as a string, independent of what may appear in the line.

Example 3.3 shows examples of **read** and **readln**.

Example 3.3

```
SIL>  a == 23;
TRUE
SIL>  b == "b;
TRUE
SIL>  begin readln(a);readln(b);
      end;
23 45
abc
 ok
SIL>  a;
23
SIL>  b;
ABC
SIL>  var a:string;;
TRUE
SIL>  read(a);
=> 'hello goodbye'
ok
SIL>  a;
hello goodbye
```

More than one item can be read from a line:

```
SIL>  a==23;
TRUE
SIL>  b==2.3;
TRUE
SIL>  begin read(a);read(b);end;
=> 1 2
ok
SIL>  a;
1
SIL>  b;
2.00000
```

Writing to the Screen

Example 3.4

Assume that we assign values to the following variables:

```
a := 9;
b := 'the value of a is ';
```

The **writeln** statement causes the interpreter to print the values of its arguments on the screen followed by a carriage return and a line feed:

```
SIL> writeln(a);
9
OK
```

The **write** statement suppresses the carriage return/line feed:

```
SIL> begin write(b); writeln(a) end;
the value of a is 9
OK
```


Reading and Writing to a File

Example 3.5

ASCII files are organized into lines. One line is specified as the current line. To perform file I/O, follow these steps.

Step 1: Declare a variable of type **text**:

```
var data : text;;
```

text is the data type of an ASCII file.

Step 2: The statement

```
data := mk_file('/people/me/my_data.txt');
```

associates the pathname **`/people/me/my_data.txt`** to the text variable data.

continued on next page

Example 3.5 (continued)

Step 3: The procedure:

open(data,'output');

allows us to write to the file with pathname **/people/me/my_data.txt**.

The procedure

open(data, 'input');

allows us to read from the file with pathname **/people/me/my_data.txt**.

A text variable cannot be simultaneously open for input and output.

WARNING The arguments to **open** are case sensitive.

Step 4: Writing to a file. Assume that data is open for output. The procedure

writeln(data,a);

writes the value of **a** to the current line of the file assigned to data, and advances the current line of data to the next line.

write(data,a);

writes the value of **a** to the next line without changing the current line.

Step 5: Reading from a file. Assume that data is open for input. The procedure

readln(data,a);

assigns the next token to the variable **a**, and advances the current line to the next line. The procedure

read(data,a);

assigns the next token to **a**, but does not advance current line.

Step 6: After any I/O session the file must be closed. The procedure

close(data);

closes data and resets its current line to the first line.

EOF

Example 3.6

Assume that data is declared, created, and opened for output as in Example 3.5. The statement

```
SIL> for i := 1 to 20 do writeln(data, i * i);
```

writes the squares of the first 20 integers to data. Assume that data is subsequently closed and re-opened for input.

```
SIL> while not eof(data) do begin readln(data,a);
     writeln(a); end;
 1
 4
 9
 16
 25
 36
 49
 64
 81
 100
 121
 144
 169
 196
 225
 256
 289
 324
 361
 400
```

Additional operations on files are

```
read_char(<text>);
read_token(<text>);
read_line(<text>);
```

Code Organization

The Soft Machines environment provides facilities for compiling and linking in SIL code. These facilities make use of a well-defined directory structure for storing the various files relevant to the system. The procedures used to compile are more complex than those used to load interpreted code, partly because the underlying structure has been set up to support the maintenance of multiple versions of compiled code. You should understand this structure before compiling your code.

All files having to do with Soft Machines reside under a master directory called **`cim`**. The collection of all Soft Machines files and directories (that is, all the files and directories under **`cim`**) is referred to as the **cim tree**. The cim tree may be located anywhere in a UNIX file system. All Soft Machines users should have a **`$CIM`** environment variable whose value is the pathname of the cim tree. It is also helpful to have a link from the home directory to the cim tree called **`~/cim`**. The following information assumes that **`~/cim`** points at the cim tree.

Code in Soft Machines is divided into modules. A **module** is simply a grouping of related code. The source code for Soft Machines itself is spread throughout approximately 100 modules—one for 2D geometry, one for 3D geometry, one for menu handling, etc. Each module may have an unlimited number of versions. The Soft Machines tree structure is set up so that different versions of the same modules share files.

Each module and each of its versions has a name. There are no hard and fast rules for naming the module and its versions, but the usual convention is

<module name>

with a version being named:

<module name><version#>

For instance, the fifteenth version of the module **`geom`** is called **`geom15`**.

The Cim Tree Structure

The following sections describe the major subdirectories of **cim**:

~/cim/templates

This directory contains all the Soft Machines products. A product contains an executable version of a Soft Machines state.

Usually, a product is started by using the Product Administration panel, which is displayed by entering **sspa** in a shell window.

To start the product **<product>**, you can also use the following commands in a shell window:

```
cd ~/cim/templates/<product>
start
```

Each product contains a **umodules** file. The **umodules** file specifies which modules are included in the product and which versions of those modules should be used.

Each line of the **umodules** file contains a module name followed by a version name.

For example, the **umodules** file of a product might consist of the two lines:

Example 3.7

```
conveyor conveyor2
press press3
```

This signifies that version 3 of the press code is to be included in this product.

~/cim/sil/<modules>

All SIL code resides in this directory. The notation **<modules>** indicates that there is one subdirectory of **~/cim/sil** for each code module.

~/cim/mccode/<modules>

All C code resides in this directory, including both C code generated from SIL and C code written "by hand."

~/cim/mhfiles/<modules>

The header (**.h**) files for C code generated from SIL are stored in this directory.

~/cim/actions/<modules>

This directory contains auxiliary information needed for SIL code. It is generated automatically by the translator, and need not concern the user.

~/cim/builds/<versions>

There is one subdirectory of **~/cim/builds** for each version of a module. Each version directory under **~/cim/builds** has the following files:

sil_files	A file listing the names of SIL files in the module
c_files	A file listing the names of hand-written C code
s	A link to **~/cim/sil/<my module>**
mc	A link to **~/cim/mccode/<my module>**
mh	A link to **~/cim/mhfiles/<my module>**
a	A link to **~/cim/actions/<my module>**

A few other directories may be present in any cim tree, but they are immaterial to the users of this manual.

Example 3.8

The following directories could exist in the press **module**:

```
~/cim/sil/press
~/cim/mccode/press
~/cim/mhfiles/press
~/cim/actions/press
```

along with three versions:

```
~/cim/builds/press1
~/cim/builds/press2
~/cim/builds/press3
```


Loading SIL Code

SIL files should be named with a .**sil** extension. To load a file containing SIL code, use this syntax:

SIL> **sil_load(<pathname>);**

For instance,

SIL> **sil_load('~/mysil/application1.sil');**

A shorter form is

SIL> **ld(<pathname-without-extension>);**

For example,

SIL> **ld('~/mysil/application1');**

sil_load commands may appear inside of files loaded using **sil_load**. This allows you to set up initialization sequences of arbitrary complexity—a master initialization file might load a series of files which in turn load other files, and so forth.

Creating a New Product

The following is a step-by-step description on how to create a new product.

1. Enter this command in a shell window:

   newproduct <product>

   This script will create the following:

   directory **~/cim/templates/<product>** file **~/cim/templates/<product>/top_init.sil** file **~/cim/templates/<product>/base*** file **~/cim/templates/<product>/umodules** directory **~/cim/gui/help/<product>**

   top_init.sil contains special initializing information for a product, **base*** are the layout configurations for the product. **umodules**, initially empty, lists the modules comprising the product. **~/cim/gui/help/<product>** is a directory to hold online help files.

2. Create at least one new module, so there is a place to put code specific for this product. To do this, enter

   newmodule <module> <first version>

   newmodule creates directories for the module as well as the first build area to include in the new product.

3. Add the following line to the file **~/cim/templates/<product>/umodules**:

   <module> <first version>

4. Copy the top bar panel from **~/cim/gui/panels/mgui** into the new module's panel area by entering

   cp ~/cim/gui/panels/mgui/top_bar ~/cim/gui/panels/<module>/top_bar

The top bar panel may then be customized using the *Visual SIL Window* for the new product.

5. Add the top bar to the new build area by editing the file **`~/cim/builds/<first version>/panels`** and adding the line

   `top_bar`

   When the product is built, the new top bar will be included.

6. Edit the product's **`top_init.sil`**, replacing the line

   `top_bar := ibase$top;`

   with

   `top_bar := <module>$top_bar;`

   When the product is built, the new top bar will replace the default.

7. Copy the file **`~/cim/gui/help/mgui/help.sil`** into the new help directory by entering

   `cp ~/cim/gui/help/mgui/help.sil ~/cim/gui/help/<product>`

8. Edit the file **`~/cim/gui/help/<product>/help.sil`** to add online help for panels new to the product. Online help is optional. The help files should be placed in the **`~/cim/gui/help/<product>`** directory.

9. Edit the **`top_init.sil`** file and add the line

   `ld('~/cim/gui/help/<product>/help');`

10. Once all code has been written and the SIL code has been compiled, enter

    `scope_out <product>`

11. For each module which contains new code, use

    `remake <module> <product>`

    to execute the second stage of compilation from C to binary.

To build the product, which will create the new executable and **heap_file**, call

rbuild <product> base

Do not use **sspa** to build products with Soft Machines, as it was not designed to work in a development environment.

Compiling SIL Code

This section contains descriptions of the procedures used to create a module of SIL and C code, to compile this code, and to create a product which includes the code.

Suppose that the module is called **ted**. If no version of **ted** exists, the following command creates a completely new module, with one version: **ted1**.

newmodule ted ted1

The **newmodule** command automatically sets up all the directories listed at the top of the page:

~/cim/mccode/ted
~/cim/sil/ted
~/cim/mhfiles/ted
~/cim/actions/ted

and

~/cim/builds/ted1

The **newmodule** command also sets up the **s**, **mc**, **mh** links in the **~/cim/builds/ted1** directory.

Example 3.9

Suppose that two SIL code files have been written (**file1.sil** and **file2.sil**) and two C code files (**cfile1.c** and **cfile2.c**) for **ted**'s application. The former files should be placed in the **~/cim/sil/ted** directory, and the latter in the **~/cim/mccode/ted** directory.

To indicate that these are the files that make up the module **ted**, we create the files **sil_files** and **c_files** in **~/cim/builds/ted1**, with the following contents:

```
sil_files:
   file1
   file2

c_files:
   cfile1
   cfile2
```

Example 3.9 shows how each of **sil_files** and **c_files** is a two-line text file giving the names of the files to be included—without the **.sil** or **.c** extensions.

Compiling the code is a two-step process. First, the SIL code is translated to C, and then compiled to binary. The first step is accomplished with a SIL command, and the second step with a shell-window command.

This SIL command

SIL> **compile_area(<module>,<version>);**

compiles all of the SIL files in the given version of the given module.

For example:

SIL> **compile_area('ted','ted1');**

compiles the SIL files for **ted**.

To compile an individual SIL file, use

SIL> **compile(<module>,<version>,<file>);**

For example:

SIL> **compile('ted','ted1','file1');**

If we are executing these commands in a product which already includes version **`ted1`** of the module **`ted`**, the version information is not necessary. In this case, the commands are

SIL> **compile_area(<module>);**

and

SIL> **compile(<module>,<file>);**

For example:

SIL> **compile_area('ted');**

SIL> **compile('ted','file1');**

Once the SIL files are compiled, the second stage of compilation (from C to binary) is accomplished via the following shell command:

remake <module> <product>

This remakes the given module for inclusion in the given product. The version used is determined from the versions file in the product. For example:

remake ted tedsproduct

In this example, the **remake** command also compiles any code included in **`c_files`**. In our example, these files are called **`cfile1`** and **`cfile2`**. Whenever SIL code is re-compiled from SIL to C, the next remake done on the module re-compiles the newly-generated C code. However, editing a hand-written C code file will not, by itself, force **remake** to re-compile that file.

To re-compile a file, add the name of the modified C file to the end of **`~/cim/builds/<version>/new_c_code`**. The next time the module is remade, the code file in question will be re-compiled.

Finally, to rebuild a product, use

rbuild <product>

Again, to create a completely new product, use

newproduct <product>

After these products and files have been created, and the relevant compiles and remakes have been done, the **rbuild** command will complete the process. After **rbuild** is finished, the **start** command starts up the product. The **rbuild** command may be used repeatedly on the same product as modifications are made and compiled into that product.

Creating New Versions

This section describes the process of adding new versions of a module to the original module. For example, suppose we wish to add enhancements to the **ted** module without disturbing the working version **ted1**. A new version of module **ted** may be created using

newversion ted ted2

This command will set up the directory **~/cim/builds/ted2**, with contents that are initially identical to those of **ted1**. Suppose next that we create a new version of our **file1.sil** SIL file, and call it **file1_2.sil**. This new version should be placed in **~/cim/sil/ted** (the same directory in which **file1.sil** resides). To compile it, use

SIL> **compile('ted','ted2','file1_2');**

To include **file1_2.sil** in **ted2**, you can simply edit **~/cim/builds/ted2/sil_files** to mention **file1_2** instead of **file1**. To include **ted2** instead of **ted1** in **tedsproduct**, we edit its version file **~/cim/templates/tedsproduct/versions**. The following command:

remake ted tedsproduct

will remake **ted2**, and

rbuild tedsproduct

will rebuild the product with **ted2**.

Including Modules and Products in the Product Administration Panel

The Product Administration panel is used to create and start new products. The panel is displayed by entering **sspa** in a shell window.

Adding New Modules

All the available modules should be listed in the Available Modules list in the Create Product panel (which is displayed by selecting *Create...* from the **Products** pulldown menu in the Product Administration panel). Modules may be made available for use in the Product Administration panel by editing the file ~/**cim/options/versions** and adding the line

```
<module> <version>
```

A module should be listed only once.

Adding New Products

All the available products should be listed in the Select Product to Start list in the Product Administration panel. Products may be made available to be built in the Product Administration panel by creating an application solution module (**appsol**), which should contain the following files:

1. **supmodules** (lists the modules to be included in the product).
2. **top_init.sil**.
3. **welcome.msg**.
4. **startup.msg**.
5. Layout files.
6. **appsol** (marking the module as an **appsol**).

The **appsol** can then be used in the Product Administration panel by first editing the file ~/**cim/options/versions** and adding the line

```
<module> <version>
```

REMINDER	A module should be listed only once.

Dependency Management

Soft Machines has a mechanism for handling dependencies between modules (build areas) which ensures that dependent and supporting modules are included during product creation.

Modules

Two files can be created and placed in the ~/**cim/build/<mybuild>** directory to supply information about any dependencies in the **mybuild** build area. These two files are

supmodules This file specifies the build areas that must come *before* the **mybuild** build area when creating a product.

comodules This file specifies the build areas that must also be included when the **mybuild** build area is included in a template (when the order is unimportant).

Both **supmodules** and **comodules** have the same syntax. Modules listed in the **supmodules** file (within the ~/**cim/build/<mybuild>** directory) will be linked in *before* the **mybuild** build area during product creation. A simple example of a **supmodules** or **comodules** file is

```
machine
paint paint14
arc
```

In this example, no version is specified for **machine**. Therefore, the current version for **machine** will be used (listed in ~/**cim/silspec/versions**). For **paint**, **paint14** is indicated. Since no version is specified for **arc**, the current version is used (listed in ~/**cim/options/versions**).

umodules

umodules is a file which can be used to specify all modules to be included in a product. The **umodules** file (which resides in ~/**cim/templates/<mytemplate>** area) has syntax like the **supmodules** and **comodules** files.

For example, to create a product with **appsup11**, the current version of **rkintf**, **arcweld7**, and the current version of **paint**, the **umodules** file would read

```
appsup appsup11
rkintf
arcweld arcweld7
paint
```

To set up your product with a **umodules** file:

1. Create a directory for your product (~/**cim/template/<mytemplate>**).
2. Create the **umodules** file.
3. Use the **ncreate_template** script (by entering **ncreate_template template_name**) to create your product.

While creating a product, **ncreate_template** calls the **scope_out** script. The **scope_out** script reads the **umodules** file, does the dependency checking and writes the traditional modules and versions files to your product area.

Using the **umodules** file is helpful when you want to remake an existing product and want to change the version of one of the modules you include, or make an addition or deletion.

"if" Syntax

supmodules, **comodules** and **umodules** files can also use **if** syntax. An example of this syntax is

```
machine machine13
paint
spot spot14
if arc
mybuild mybuild12
appsup
fi
```

In this example, **machine** version 13 is specified, the current version of **paint** is specified, and **spot** version 14 is specified. Then, the **if** block indicates that if (any version of) **arc** is included in the build, then **mybuild** version 12 and the current version of **appsup** should also be included.

"Support Only" Builds Areas

A builds area which is used only as a supporting module for some other builds area(s) can be marked so that it is not offered to the user as an option when using the Product Administration panel (**sspa** script) to create a product. To mark a builds area as "support only," create an empty directory in the supporting module build area with the name: **support_only**.

Application Solutions Header Module

If your project involves a number of builds areas, you can create an application solutions header module.

To do this, make an entry in the ~/**cim/options/versions** file and create a directory in the ~/**cim/builds** directory (such as **MYPROJECT1.0**). Within that directory, create an empty file called **appsol**, and a **comodules** and/or **supmodules** file.

When you use the Product Administration panel to create a product, and you select your application solution (**`MYPROJECT1.0`**), all of the **`comodules`** and **`supmodules`** files from the builds areas which comprise the application solution will be read.

Based on the information that is read, the Product Administration panel will create a new modules file and write it to your product area. All the components of the application solution will be included in this newly created modules file. Various initialization files and **`start_up.msg`** will also be copied from the application solution (**`MYPROJECT1.0`**) to your product area.

Patching in Interpreted Code

SIL allows interpreted versions of functions to overwrite their compiled versions. For instance, suppose that a function, **`teds_function`**, has been compiled into a product. If we wish to test a modification to this function, we can load or paste in a new version of code for the function, and the new code will take effect immediately. That is, whenever **`teds_function`** is called by any other function in the system (whether compiled or interpreted), it is the most recently-loaded version that is called—*not* the original compiled version. The process of overwriting compiled with interpreted code for a function is called **patching** the function. The ability to patch code is very useful, since it allows code to be enhanced, tested, and debugged without going through a compile and link cycle.

Debugging

Whenever possible, debugging should be done with Soft Machines in Text Mode. Catching errors while still using the menus and panels is discussed at the end of this section.

REMINDER	Text Mode is obtained by selecting *Exit Menus* from the **File** pulldown menu. In Text Mode, the menus and panels are disabled and the SIL> prompt is displayed in the shell window you used to start the session.

When an error occurs while running SIL in Text Mode, an error message is printed, along with the following prompt instead of the SIL prompt:

```
Error>
```

The Error> prompt indicates that an error break has occurred. During an error break, any SIL command is legal. In addition, the call stack becomes accessible for examination. The **call stack** is a data structure which describes the function which was running when the error occurred, and the sequence of function calls which led to the function invocation. The call stack also contains the values of all local variables in the functions on the stack.

This SIL command is used to examine the stack by printing a trace back:

```
Error>  tb();
```

Example 3.10 shows a typical function, function call, error message and trace back.

Example 3.10

Consider the functions

```
function blow_up(x:string):string;
var z:string;
begin
    z := null_string;
    for i := 1 to 10 do
    begin z := x * z;
        error('blow up error');
    end;
    blow_up := z;
end;

function calls_blow_up(x:string):string;
var y:string;
begin
    y := x * x;
    calls_blow_up := blow_up(y * '_blow_up');
end;
```

Then

```
SIL>  calls_blow_up('bang');
error: blow up error
("SIL break")
"in nSIL_error"
"r(); to return"
Error>
```

continued on next page

Example 3.10 (continued)

Using the command **tb();** gives these results:

```
Error>    tb();
0     I_TEVAL(LISPOB)
1     I_TEVAL1(LISPOB)
2     PM_EXECUTE(IFORM)
3     CALLS_BLOW_UP environment:
   ARG X = bang
         Y = bangbang
         G3_CALLS_BLOW_UP = <NULL S_T_R>
4     BLOW_UP environment:
   ARG X = bangbang_blow_up
         Z = bangbang_blow_up
         I = 1
         _S_33 = 1
         _S_34 = 10
         G2_BLOW_UP = <NULL S_T_R>
5     POST_ERROR_FUN()
```


The numbers in the **0** column are the indices of the stack frames, and are called **frame numbers**. These numbers are used to refer to frames in commands described in the succeeding pages. The values of all local variables, including parameters, are printed (parameters, however, are labeled **ARG**).

In Example 3.10, the frames numbered **0**, **1**, **2**, and **5** designate system functions, while **3** and **4** are the frames of the user functions **calls_blow_up** and **blow_up**.

The **tb** command works for both interpreted and compiled code. When it is used with compiled code, however, only function names (and not local values) are available. To see the values of local values in the compiled code for a function, we can patch in its source code, and the local values for that function will be available to **tb** and other stack examination facilities. This means we do not need to regenerate the error using interpreted code to see local values—patching the function into the existing error break is adequate.

If **tb** is given an integer argument, only the specified number of frames above the debug frame will be printed. For example, the following **tb** command, with its argument, would only print frames **4** and **5** from Example 3.10:

Error> **tb(2);**

The command

Error> **tbn();**

is identical to **tb**, except that it prints no local or parameter values. Example 3.11 illustrates the use of the **tbn** command:

Example 3.11

```
Error>  tbn();
0     I_TEVAL(LISPOB)
1     I_TEVAL1(LISPOB)
2     PM_EXECUTE(IFORM)
3     CALLS_BLOW_UP(S_T_R)
4     BLOW_UP(S_T_R)
5     POST_ERROR_FUN()
ok
```

The following command returns the value of the given variable in the given frame as a universal:

Error> **ev(<variable name>,<frame number>);**

For example:

Example 3.12

```
Error>  ev(y,3);
[UNIVERSAL: bangbang OF_TYPE STRING]
```

The **debug_frame** variable is initially set to the frame number of the function in which the error occurred. The following commands are equivalent:

Error> **ev(<variable name>);**

Error> **ev(<variable name>,debug_frame);**

You are free to reset **debug_frame**, thus changing the behavior of the single argument variant of **ev**.

In our example, the error was caused by an explicit SIL error statement. Other errors arise from the usual UNIX error conditions: access violations, arithmetic errors, interrupt signals, etc. Regardless of the source of the error, the behavior of the error break is the same.

The command

```
Error> r();
```

returns control to the top level SIL loop; that is, it exits the error break and cleans up the stack. Continuing from the error along the same course of computation that caused the error is not possible. However, you can include statements in your code which will cause a **pause break** (a break with behavior identical to an error break but one from which computation can be continued using the **go** command. This command is

ppause(x:string);

Using the command and argument above results in x being printed out when the pause break is entered. Example 3.13 provides an extended example of **ppause**.

Example 3.13

```
procedure test_pause(n:integer);
    begin
    for i := 1 to n do ppause('testing');
    end;

SIL> test_pause(20);
pausing at testing
go; to continue
```

continued on next page

Example 3.13 (continued)

```
Pause>  tb();
0     I_TEVAL(LISPOB)
1     I_TEVAL1(LISPOB)
2     PM_EXECUTE(IFORM)
3     TEST_PAUSE environment:
   ARG N = 2
         I = 1
         _S_39 = 1
         _S_40 = 2
4     PPAUSE(S_T_R)
ok

Pause>  Pause> go;
pausing at testing
go; to continue
Pause> tbn();
0     I_TEVAL(LISPOB)
1     I_TEVAL1(LISPOB)
2     PM_EXECUTE(IFORM)
3     TEST_PAUSE(INTEGER)
4     PPAUSE(S_T_R)
ok

Pause>  ev(i,3);
[UNIVERSAL: 2 OF_TYPE INTEGER]

Pause>  go;
ok

Pause>  r();
Restarting…
Unwinding stacks…
Debug version of SIL

SIL>
```

Debugging in Menu Mode

This section discusses debugging code which causes errors while you are still using the menus and panels. The following SIL flag:

to_text_mode_on_error

controls what happens when an error condition is encountered in menu mode. When the flag is set to **true**, any error encountered by the system will cause Soft Machines to switch to Text Mode automatically, and display the ERROR> prompt. This flag is useful when tracking bugs. The default setting of the flag is **false**. When it is set to **false**, errors are reported, but panels stay up and no error prompt results.

Calling C Code from SIL

This section describes how C code can be called from SIL. This section includes the following topics:

- Sample .c and .h Files
- *Passing Data Types to C*

REMINDER	The procedure for including hand-written C code in a module was discussed in “Loading SIL Code” on page 3-11.

The following command imports the given C function and assigns it the given SIL type:

c_import("<function name>,<type>);

For example:

c_import("foo,map(integer,integer));

will import a C function **foo** on integers. After that process is complete, **foo** can be treated just like any other SIL function on integers—it can be called freely from SIL code, as in

```
SIL> for i := 1 to 10 do writeln('foo of ', i, ' = ', foo(i));
```

The only restriction is that the SIL file in which the **c_import** occurs must be compiled—not interpreted. Furthermore, patching over a compiled **c_import** will prevent it from functioning thereafter.

Importing a C function into SIL is quite simple. For integers and reals, only a **c_import** command is needed. One restriction exists: all C functions imported into SIL must obey the "reals last" rule which requires real parameters to appear after parameters of other types in the parameter list. lrecords or arrays can be used to pass structured data back and forth to C. C code may read values from these lrecords and arrays, and stuff new values into them as a way of returning structured data. Alternatively, the types described in "C Data Types" on page 7-14 may be used to create data structures in SIL which are identical to C data structures, and can be freely shared between SIL and C code. The only style of sharing which will not work is to attempt to build SIL data structures like lrecords and SIL arrays in C code. This is because all structured data in SIL needs to be allocated in a way that is consistent with garbage collection methods in SIL, so simple C mallocs will not do.

NOTE SIL integers correspond to the C type **int**, and SIL reals correspond to the C type **double**.

Interfacing to Existing C Code

Of course, in many applications, the task will be to interface to an existing body of C code, rather than to write new C code for use with SIL. In the former case, unless it is very simple, wrappers written in C will be needed for transporting data between SIL and the application.

Sample .c and .h Files

The remaining issue is what C declarations should be given to inputs from SIL. SIL provides a facility for automatically generating such declarations. Namely, whenever a SIL file which contains **c_imports** is compiled, sample **.c** and **.h** files are generated. These sample **.c** and **.h** files contain these declarations, and samples of their use. The sample files are placed in

```
~/cim/mccode/<module>/<filename>_sample.c
```

and

~/cim/mhfiles/<module>/<filename>_sample.h

These sample files are meant to be copied to your own files (with different names so that they will not be overwritten), where the function bodies will be filled in.

IMPORTANT	The **include** line in the **.c** file which mentions the sample **.h** file should be changed.

Alternatively, the sample files may be used solely as documentation. The types which will appear in the sample **.h** file will include all those referenced in the **c_import** commands—not just those that happen to be defined in the file containing the **c_import** commands.

Example 3.14

Suppose that the following types have been defined:

```
type lpoint = lrecord
    xc,yc,zc:real;
    end;

type point = record
    xc,yc,zc:real;
    end;;
```

Suppose further that the file **~/cim/sil/ted/ted.sil** has the contents:

```
c_import("cfun1,map(integer,point,real));
c_import("cfun2,map(lpoint,lpoint,real));
c_import("cfun3,map(integer,darray of real, list of ob,
darray of lpoint,
darray of point));
```

The following sample files would be generated.

continued on next page

Example 3.14 (continued)

```
~/cim/mhfiles/ted/ted_sample.h:
/* SAMPLE .h FILE */
        struct point {
           integer typenum_field;
           real xc;
           real yc;
           real zc;
        };
        typedef struct point *pointp;
        struct lpoint {
           integer typenum_field;
           real xc;
           real yc;
           real zc;
        };
        typedef struct lpoint *lpointp;
        typedef real *real_array;
        typedef lpointp *lpointp_array;
        typedef struct point *point_array;

 ================ END OF FILE  ================
```

continued on next page

Example 3.14 (continued)

```
~/cim/mccode/ted/ted_sample.c:
/* SAMPLE .c FILE */
        #include "compiled.h"
        #include "precomp.h"
        #include "e2c.h"
        #include "ted_sample.h"
        #include "postcomp.h"

        integer cfun1(a0,a1)
        point a0;
        real a1;
        {
        /* FUNCTION BODY */
        }


        lpointp cfun2(a0,a1)
        lpointp a0;
        real a1;
        {
        /* FUNCTION BODY */
        }


        integer cfun3(a0,a1,a2,a3)
        real_array a0;
        lispob a1;
        lpointp_array a2;
        point_array a3;
        {
        /* FUNCTION BODY */
        }

================= END OF FILE ==================
```

Passing Data Types to C

Passing Records to C

Records, as well as **lrecord**s, can be passed to C. Records are passed by reference, even though they are passed to SIL functions by value. No problems will arise from passing records to C, but attempting to return values in records, rather than **lrecord**s, is discouraged.

A SIL **lrecord** or record type **<type>** generates a corresponding **struct** declaration of the same name, and defines **<type>p** to be the type of pointer to this type. **<type>p** is the type assigned to incoming arguments from SIL. Since passing of records and **lrecord**s to C is identical, the type **lpoint** and **point** generate C declarations of identical structure. Notice, however, that an array of points and an array of **lpoint**s differ—the former is given by a pointer to a point and the latter by a pointer to a pointer to an **lpoint**.

Passing Other SIL Types

The SIL type **string** is passed to C as **stringob** (discussed further in the “Protecting the Data Space when Passing Strings” on page 3-39). The rest of the SIL types (excluding the ones already mentioned) are passed simply as **lispob**. The sample C file starts with a few includes. These inclusions bring in various basic definitions associated with the underlying implementation of SIL in C. It is here that the types **stringob**, **lispob**, **real** and **integer** are defined.

Passing a SIL Array

A SIL array is passed to C as a pointer to some header information used in SIL—not to the beginning of the array itself. The first element of the array is arrived at by using the macro **ARRAY_BODY**, and its length by **array_length**.

Example 3.15 provides a more complete example, in which functions for doubling an **lpoint** and for doubling an array of points are imported.

Example 3.15

First import the file (**`ted2.sil`**):

```
c_import("double_it,map(integer,lpoint));
c_import("adouble_it,map(integer,darray of point));
```

Compilation of this file yields the sample files shown below.

```
~/cim/mhfiles/ted/ted2_sample.h:
/* SAMPLE .h FILE */
        struct lpoint {
           integer typenum_field;
           real xc;
           real yc;
           real zc;
        };
        typedef struct lpoint *lpointp;
        struct lpoint {
           integer typenum_field;
           real xc;
           real yc;
           real zc;
        };
        typedef struct point *pointp;
        typedef struct point *point_array;

 ================ END OF FILE ================
```

continued on next page

Example 3.15 (continued)

```
~/cim/mccode/ted/ted2_sample.c:
/* SAMPLE .c FILE */
        #include "compiled.h"
        #include "precomp.h"
        #include "e2c.h"
        #include "ted2_sample.h"
        #include "postcomp.h"

        integer double_it(a0)
        lpoint a0;
        {
        /* FUNCTION BODY */
        }


        integer adouble_it(a0)
        point_array a0;
        {
        /* FUNCTION BODY */
        }
 ================END OF FILE  ================
```

Next, the sample files are copied to files renamed cted2:

~/cim/mccode/ted/ted2_sample.c is copied to **~/cim/mccode/ted/cted2.c** and

~/cim/mhfiles/ted/ted2_sample.h is copied to **~/cim/mhfiles/ted/cted2.h**.

continued on next page

Example 3.15 (continued)

cted2.h does not need modification. Filling in the code for **cted2.c** yields:

```
#include "compiled.h"
#include "precomp.h"
#include "e2c.h"
#include "cted2.h"
#include "postcomp.h"

integer double_it(a0)
lpoint a0;
{
     a0 -> xc = 2 * a0 -> xc;
     a0 -> yc = 2 * a0 -> yc;
     a0 -> zc = 2 * a0 -> zc;
}

integer adouble_it(a0)
point_array a0;
{
point_array a0_goods;
integer ln,i;
in = array_length(a0);
a0_goods = (point_array)ARRAY_BODY(a0);
for (i=0;i<ln;i++)
   double_it(&(a0_goods[i]));
}
 ================ END OF FILE ================
```

This is C code which actually doubles the entities in question. To install this work in the **ted2** version of the module **ted**, add the following line to **~/cim/builds/ted2/sil_files**:

ted2

and the line

cted2

to **~/cim/builds/ted2/c_files**

continued on next page

Example 3.15 (continued)

After a **remake** and **rbuild**, the imported C code is available:

```
SIL> double_it(mk_lpoint(1,2,3));
2184488

SIL> ll == mk_lpoint(1,2,3);
TRUE

SIL> ll
[LTUPLE: 6.000000,4.000000,6.000000]

SIL>
```

NOTE **double_it** returns a "garbage value" because the code for **double_it** did not bother to execute a return. This is harmless.

```
SIL> aa == array_create(point,4);
TRUE

SIL> for i := 0 to 4 do aa[i] := [i,i,i] as point;
ok

SIL> aa;
[ARRAY: [TUPLE:
0.000000,0.000000,0.000000],[TUPLE:
1.000000,
1.000000,1.000000],[TUPLE:
2.000000,2.000000,2.000000],[TUPLE:
3.000000,3.000000,3.000000],[TUPLE:
4.000000,4.000000,4.000000]

SIL> adouble_it(aa);
11612136

SIL> aa;
[ARRAY: [TUPLE:
0.000000,0.000000,0.000000],[TUPLE:
2.000000,
2.000000,2.000000],[TUPLE:
4.000000,4.000000,4.000000],[TUPLE:
6.000000,6.000000,6.000000],[TUPLE:
8.000000,8.000000,8.000000]
```

Protecting the Data Space when Passing Strings

As mentioned earlier, SIL strings are passed to C with the type **stringob**. SIL strings differ from C strings in that they include a header which consists of a type tag and a length, and are not necessarily null-terminated—the length field in the header determines how long the string is, not the first occurrence of a **nul** in the sequence of bytes which make up the string. The C function **strlen** will return the length of a **stringob**, while **STRING_BODY** will yield a pointer to the beginning of the string itself. The functions **l2c_str** and **c2l_str** convert back and forth between the SIL and C representations of strings: **l2c_str** converts from SIL to C strings, and **c2l_str** should only be used to return a single value directly to SIL, as in

```
return c2l_str(<a C string>);
```

If **c2l_str** is not used in this fashion, the data space of SIL may be corrupted.

Chapter 4

Geometry in Soft Machines

This chapter explains the geometric terms used in Soft Machines and contains instructions for manipulating geometry with SIL commands instead of the menus. These instructions are provided for programmers who need a fairly detailed guide for performing geometric manipulations.

Understanding Soft Machines Geometry

Spatial geometry or simply, geometry* is the means of describing how objects are situated in the region of three-dimensional space being simulated.

With Soft Machines, geometric descriptions are used to construct and locate simulated objects. Soft Machines uses those same geometric descriptions to perform kinematic transformations on the simulated objects for moving them around the simulated space.

Geometric Terms

The language used in this manual and when speaking about Soft Machines entities contains terms like **coordinate system**, **frame**, **pose**, and **reference system**. The following items explain the distinctions between these terms:

- All shapes have a pose.
- Frame shapes are a special kind of shape (which also possess a pose).
- The current reference frame is some shape's pose.
- Frame shapes are physical objects in the simulated world, and can usually be picked with the mouse like any other shape.
- Poses can be displayed, but are ephemeral—they cannot be selected.

* Chapter 2 of *Introduction to Robotics* by John J. Craig (Addison-Wesley, 1989) provides detailed information on the concepts in this chapter.

Every point on an object has a fixed location relative to its pose. When you manipulate objects, you only need to be concerned with their poses.

> **NOTE** "Poses" on page 4-16 describes poses.

Shape

To simulate objects in a three-dimensional space, Soft Machines manipulates a data structure in which all simulated objects are represented by a type called **shape**.

To handle multiple shapes, Soft Machines arranges all shapes in the simulated world in a tree structure. The root of this tree is a special shape which lacks any associated geometry and is called **`world`**.

Frame

Soft Machines provides a special kind of shape called a **frame** which is used primarily for teaching desired positions of objects (e.g., via points in a path along which another shape will move). The geometry of a frame shape is shown on the right-hand side of Figure 4-1—one axis looks like an X, one like a Y, and the Z axis looks like a pointer. Because a frame is also a kind of shape, it has a pose which lies coincidently with the frame's geometry.

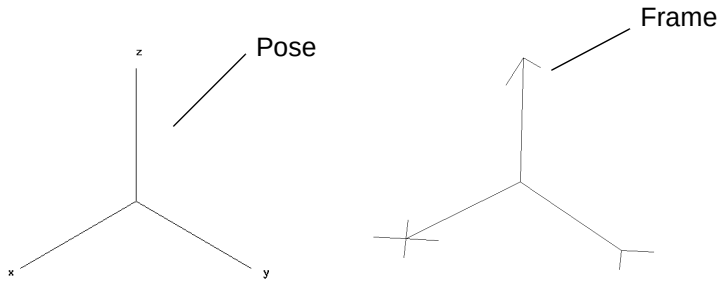


Figure 4-1 Coordinate frames

Geometric Units

To specify positions and orientations, you need a way of specifying lengths and rotations.

The default unit for length in Soft Machines is centimeters. All other units of length are based on this default and are easily defined.

Example 4.1

To use the meter (100 centimeters) as your default unit. This unit is defined with a SIL **const** declaration:

```
const meter := 100;
```

To express a length in meters rather than in centimeters, the length is simply multiplied by the constant. For instance, a length of 5 meters would be written as

```
5 * meter
```

Some units of length are already pre-defined as global constants in Soft Machines. They are inch (2.54 centimeters), foot (30.48 centimeters), mm (0.1 centimeters), and mil (0.00254 centimeters).

The default unit for rotation is degrees. The size of a rotation is the number of degrees in the swept angle. **Positive (+) rotations** are taken to be counter-clockwise looking down the positive axis of rotation toward the plane of rotation. **Negative rotations** are clockwise. A pre-defined constant rad (180/pi degrees) is provided for working in radians.

The following equation returns a value of 180:

```
pi * rad;
```

Position

A **position** is a property of points that describes a point's location relative to some known reference frame. The position of the point is at X, Y, Z in Cartesian coordinates. In Soft Machines, the units of position are specified by centimeters by default (but can be changed easily to the units of your choice).

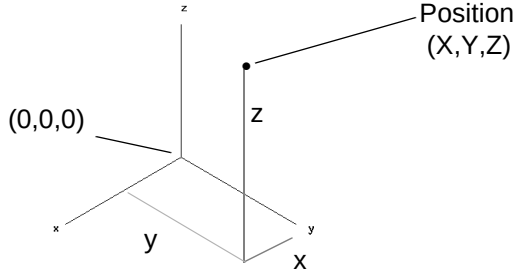


Figure 4-2 Position

For example, every point on an object has a position relative to the frame of that object. Every frame has a position relative to some other frame determined by the location of its origin (a point) in that frame. A convenient way to depict position is with a vector pointing from the reference frame's origin to the positioned point.

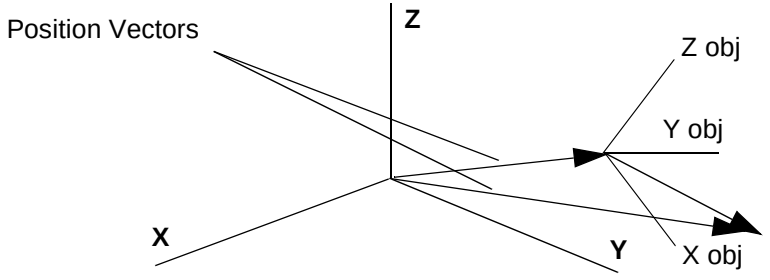


Figure 4-3 Position vectors

A point's position is specified by its reference frame coordinates. Soft Machines provides three useful coordinate descriptions: Cartesian, cylindrical and spherical.

Cartesian Description

The most common is the Cartesian description where the point's coordinates are its X, Y, and Z distances from the reference frame's origin.

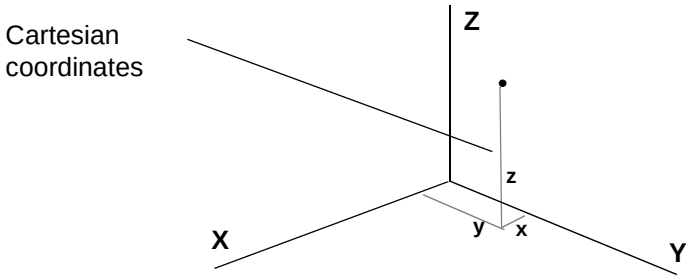


Figure 4-4 Cartesian coordinates

Use the type **crt** to construct a Cartesian position using this command and syntax:

mk_crt(<xc>,<yc>,<zc>);

or

mk_point(<xc>,<yc>,<zc>);

Cylindrical Description

Another type of position is the cylindrical description in which the point's coordinates are its angular distance from the X axis measured counter-clockwise in the XY-plane of the reference frame, its radius normal to the Z axis, and its height along the Z axis.

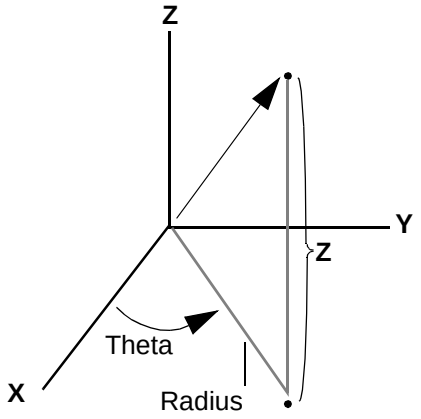


Figure 4-5 Cylindrical coordinates

Use the type **cyl** to construct a cylindrical position using this command and syntax:

mk_cyl(<rad>,<theta>,<zc>);

Spherical Description

The final description is spherical, in which the point's coordinates are its radius from the origin of the reference frame, its angular distance from the X axis (longitude), and its angular distance from the XY-plane (latitude).

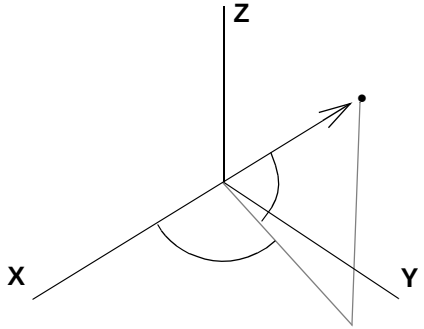


Figure 4-6 Spherical coordinates

Use the type **sph** to construct a spherical position using this command and syntax:

mk_sph(<rad>,<lng>,<lat>);

Orientation

Orientation is a property of objects that describes how the object's frame is aligned relative to a reference frame. Orientation is specified in terms of rotations of the object's frame about the axes.

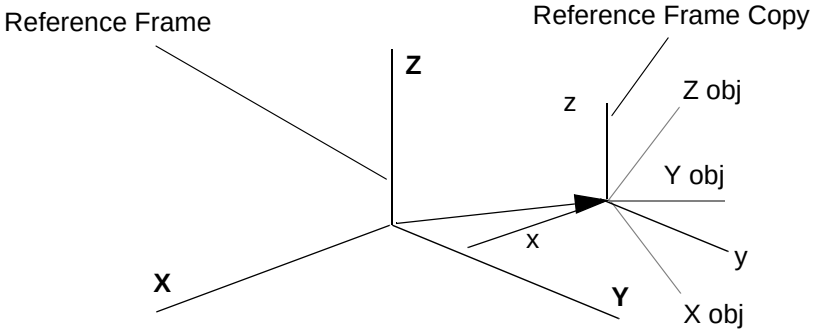


Figure 4-7 Orientation

With the two frames initially coincident, the rotations are performed in a specific order to arrive at the stated orientation. Using a copy of the reference frame is important to prevent inadvertent position changing. That is, if the rotations are conducted about the axes of the reference frame itself, the position and the orientation will change.

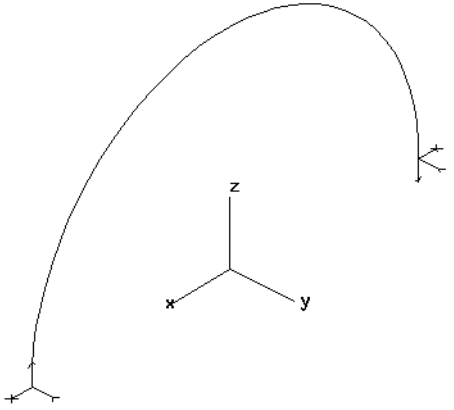


Figure 4-8 Frame rotated about Y axis

Using Soft Machines, there are three main ways to specify the rotations that describe the orientation of a frame:

- Sequential rotations of the frame about the fixed X, Y, and Z axes of the reference frame copy (called **yaw-pitch-roll**).
- Sequential rotations about the X, Y, and Z axes of the frame's new orientation after each successive rotation (called **Euler angles**).
- A single rotation of the frame about a generalized axis pointing out from the origin of the reference frame copy (called **equivalent angle-axis**).

Within the **Euler** and **fixed** representations, there are 24 combinations for specifying orientations. Use the input representation from the following list which matches your situation, and the SIL function **to_frame**, to convert general orientations to Soft Machines frames.

xyz_fixed	**yzx_fixed**	**xyx_fixed**	**yzy_fixed**
xyz_euler	**yzx_euler**	**xyx_euler**	**yzy_euler**
xzy_fixed	**zxy_fixed**	**xzx_fixed**	**zxz_fixed**
xzy_euler	**zxy_euler**	**xzx_euler**	**zxz_euler**
yxz_fixed	**zyx_fixed**	**yxy_fixed**	**zyz_fixed**
yxz_euler	**zyx_euler**	**yxy_euler**	**zyz_euler**

Yaw-Pitch-Roll

In Soft Machines terminology, **yaw**, **pitch**, and **roll** refer to rotation about the X, Y, Z axes (in that order) about a fixed reference frame. In the case of robot end-effectors, the Z axis points outward along the centerline of the flange. Therefore, the roll of the wrist always occurs about the Z axis of the tool or mounting flange (see Figure 4-9).

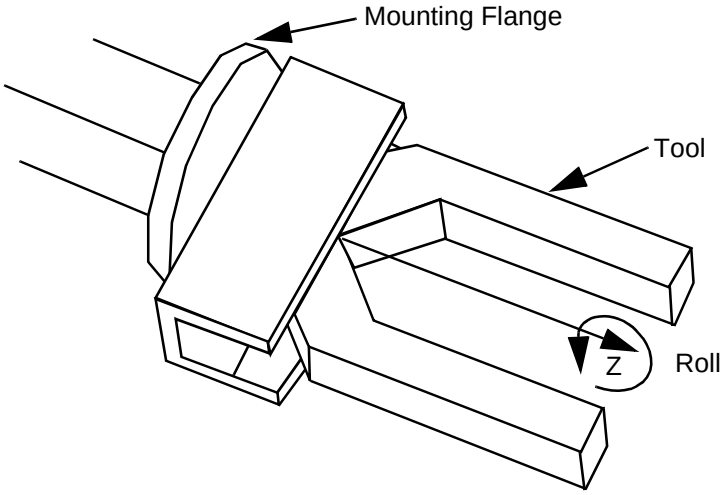


Figure 4-9 Yaw-Pitch-Roll

Yaw-pitch-roll is convenient for describing the orientation of any object's frame. The rotations are performed sequentially about the axes of the initial orientation of the frame and always performed in this order:

1. yaw (about X)
2. pitch (about Y)
3. roll (about Z)

The order in which the rotations are performed is important. In general, a rotation about x followed by a rotation about y followed by a rotation about z (yaw-pitch-roll) will not produce the same orientation as a

rotation about Z, then about Y, then about X (roll-pitch-yaw). Figure 4-10 shows the difference between a yaw-pitch-roll of (90,90,90) and a roll-pitch-yaw of (90,90,90).

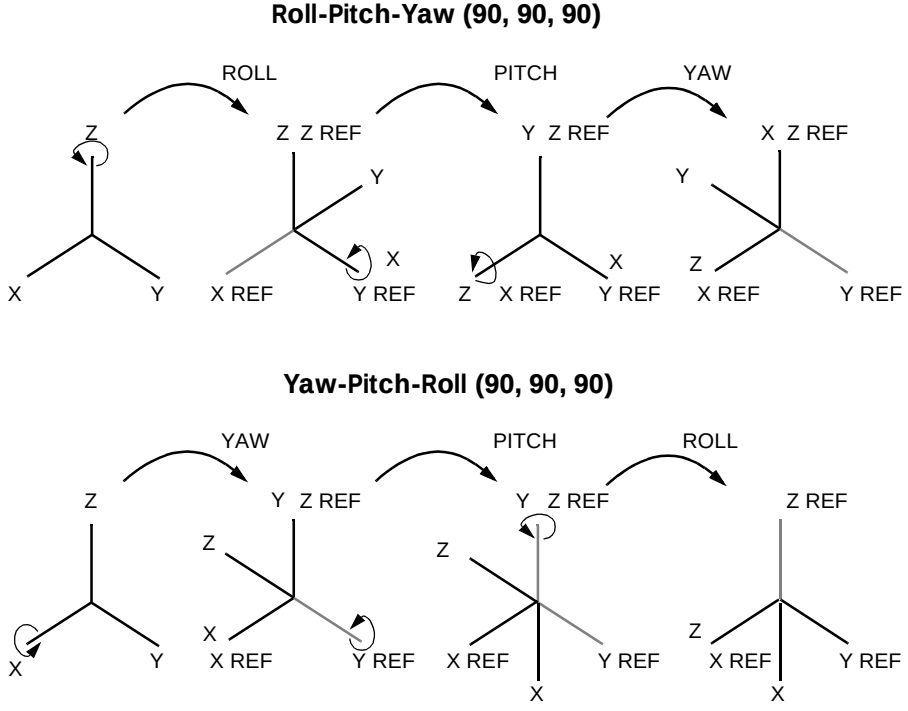


Figure 4-10 Roll-Pitch-Yaw vs. Yaw-Pitch-Roll

For mnemonic reasons, the rotations will always be performed in the order in which they are specified. Because X-Y-Z is a familiar order, yaw-pitch-roll is only used in Soft Machines for rotations about the (fixed) axes of the reference frame copy. Because all three rotations are defined relative to the same initial frame orientation, these rotations are relative to fixed axes. This is a key point since Euler angles are rotations which are not relative to fixed axes.

The geometric type provided by SIL for describing yaw-pitch-roll orientations is **ypr** (yaw-pitch-roll). You may construct a yaw-pitch-roll orientation with the command

mk_ypr(<yaw>,<pitch>,<roll>);

Euler Angles

Euler (pronounced “oiler”) angles are named after a Swiss mathematician, Leonhard Euler (1707-1783), who contributed many important theorems to the science of kinematics. Like yaw-pitch-roll, Euler angles describe orientation by sequential axis rotations. The difference is that the rotations are not about the axes of the fixed reference frame copy as they are with yaw-pitch-roll rotations; they occur about the new axes of the frame after each rotation.

In general, any series of three rotations in which each successive rotation is about one of the new X, Y, or Z axes is a set of Euler angles. For example, one commonly used convention is Z-Y-Z Euler angles. An orientation given in Z-Y-Z Euler angles is the result of first rotating the frame about the Z axis of the reference frame copy with which it is initially coincident, then rotating about the new Y axis and, finally, rotating about the new Z axis. Many six degree of freedom robots have wrists which emulate this Z-Y-Z orientation.

The geometric type provided by SIL for describing Z-Y-Z Euler angle orientations is **zyz** (Z axis, Y axis, Z axis). A Z-Y-Z Euler angle orientation may be constructed with the command:

mk_zyz(<rotz1>,<roty>,<rotz2>);

Another Euler angle set is X-Y-Z. An orientation given in X-Y-Z Euler angles is the result of first rotating the frame about the X axis of the reference frame copy with which it is initially coincident, then rotating about the new Y axis and, finally, rotating about the new Z axis.

The geometric type provided by SIL for describing X-Y-Z Euler angle orientations is **xyz** (X axis, Y axis, Z axis). You may construct an X-Y-Z Euler angle orientation with the command

mk_xyz(<rotx>,<roty>,<rotz>);

As with yaw-pitch-roll, the order in which the rotations are performed is crucial in describing orientations using either set of Euler angles.

Equivalent Angle-Axis

One of Euler's theorems states that any orientation may be achieved with an appropriate rotation of the frame about a general axis through the origin of the reference frame copy. This is called the **equivalent angle-axis** rotation.

The equivalent axis of rotation may be represented as a unit vector from the origin of the reference frame copy. The formula for finding a unit vector from a set of XYZ Cartesian coordinates through which the positive axis of rotation passes is:

$$u = \frac{a}{|a|}$$

where u is the desired unit vector, a is the Cartesian point in vector form, and:

$$|a|$$

is the vector magnitude of a.

For instance, a unit vector through the Cartesian point (1,1,1) is:

$$\left(\frac{\sqrt{3}}{3}, \frac{\sqrt{3}}{3}, \frac{\sqrt{3}}{3}\right)$$

A unit vector through the point (1,2,0) is:

$$\left(\frac{\sqrt{5}}{5}, \frac{2\sqrt{5}}{5}, 0\right)$$

A unit vector along the X axis is simply (1,0,0). The equivalent angle-axis representation is constructed by multiplying the unit vector of the equivalent axis by the equivalent angle.

The geometric type provided by SIL for describing equivalent angle-axis orientations is **aax** (equivalent angle-axis). You may construct an equivalent angle-axis orientation with the command

mk_aax(<xeq>,<yeq>,<zeq>);

Although it is not easy to determine the appropriate general axis and proper rotation to produce a desired orientation, the equivalent angle-axis representation is useful for producing complex orientations when you know both the axis and amount of rotation. Consider the antenna in Figure 4-11.

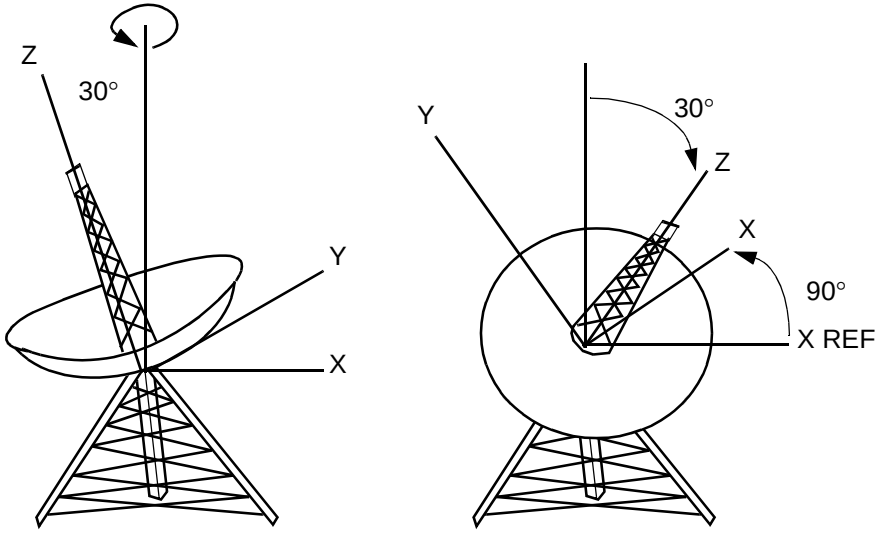


Figure 4-11 Angle-axis orientation

The Z axis of the dish's frame is normal to the dish at its center, and is tilted 30 degrees from vertical in its YZ-plane. To rotate the dish 90 degrees while maintaining the same tilt, you must determine the unit vector of rotation along the vertical axis in the dish's frame (which is 0,sin30,cos30). Next, multiply the vector by the desired rotation of 90. The resultant orientation (with respect to the initial orientation) is

```
[0,45,77.9] as aax
```

When orientations involve only a single rotation about the X, Y, or Z axis of the reference frame copy, it makes no difference whether you describe them using yaw-pitch-roll, X-Y-Z Euler angles, or equivalent angle-axis. For example, the following commands each describe the same orientation:

```
[0,70,0] as ypr;
[0,70,0] as xyz;
[0,70,0] as aax;
```

Figure 4-12 illustrates that this is not the case for orientations involving more than one principle axis rotation.

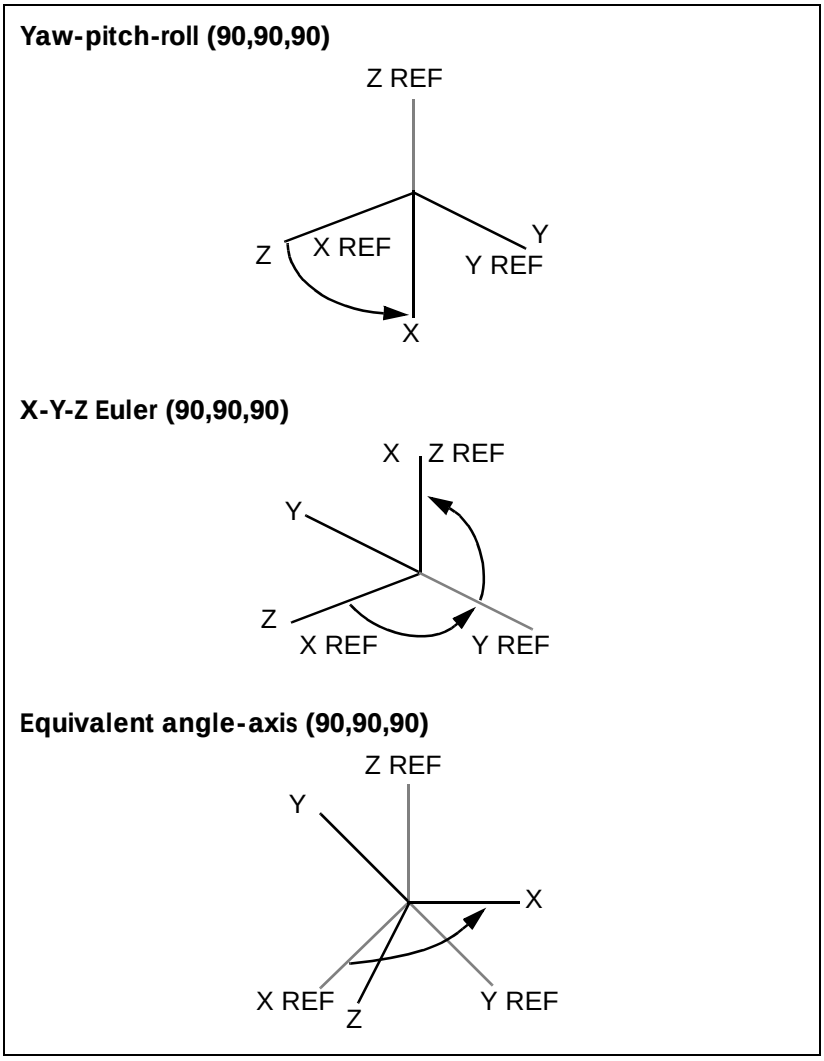


Figure 4-12 Orientations with multiple axis rotations

Poses

Every shape (including World) has an associated local reference frame which is called its **pose**. The pose of the World is the master reference system, and every other shape in the World tree has a pose which is specified relative to the World pose. When you select a reference frame using the menus, the pose of some shape is always selected. The default reference frame is the pose of the World and may sometimes be called the Universe **coordinate system**.

In Soft Machines, a pose is described using six values that combine its position and orientation (**x**, **y**, **z**, **yaw**, **pitch**, **roll**).

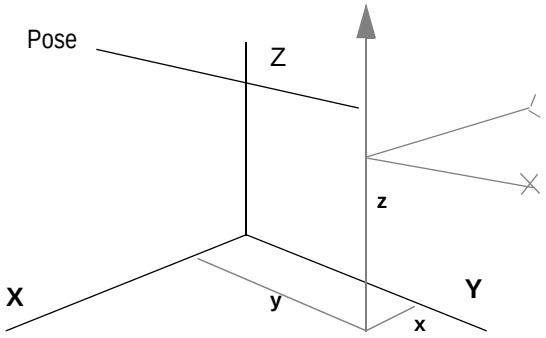


Figure 4-13 Pose

Describing position and orientation is simply a matter of combining a position and orientation using the geometric type **pose**. The general form of the command is

mk_pose(<position>,<orientation>);

where <**position**> and <**orientation**> may be any of the types described above. Either or both position and orientation may be specified. If you omit position, it is assumed to be (0,0,0). Likewise, if you omit orientation, it is assumed to be (0,0,0).

For added convenience, a pose may be specified with six numbers. The first three indicate the Cartesian position, and the last three indicate the yaw-pitch-roll orientation:

mk_pose(<xc>,<yc>,<zc>,<yaw>,<pitch>,<roll>);

This Cartesian yaw-pitch-roll description is the default of poses used in Soft Machines.

Example 4.2

Some examples specifying poses are:

```
mk_pose(mk_sph(1,2,3),mk_ypr(90,0,30);
mk_pose(position_1,mk_xyz(30,45,0));
mk_pose(table_orientation);
mk_pose(30,50,74.2,90,90,0);
```

As an aid in visualizing poses, they can be displayed as frames using the **show** command:

```
show(<pose>);
```

The specified pose will be displayed as a frame whose origin is the point specified by the position component of the pose, and whose axes represent the orientation component of the pose. Poses displayed with the **show** command remain visible as frames only temporarily—they disappear the next time the graphics display is updated.

Geometric Operators

All positions, orientations, and poses are absolute. In other words, the assumed reference is the Universe frame whose pose is the null (absolute) pose described in Cartesian and yaw-pitch-roll terms as (0,0,0,0,0,0).

You may find it convenient to think of poses in relation to reference frames other than the Universe frame. For instance, given cutter machining a part, it is easier to specify the pose of the cutter relative to the frame of the part rather than to the Universe frame, especially if the absolute pose of the part is unknown beforehand. To do this, use the geometric operator **rel** to specify a reference frame. The general command form of the **rel** operator is

```
<geometric type>rel<pose>;
```

where the argument preceding **rel** can be any position, orientation, or pose, and the argument following **rel** must always be a pose. The value returned is always an absolute position, orientation, or pose computed from the two arguments. For example, consider a pose of (1,2,3,0,0,0). A position (1,3,2) relative to this pose would be the position (2,5,5) in the Universe frame. That is,

```
mk_crt(1,3,2) rel mk_pose(1,2,3,0,0,0);
```

returns the Universe position (2,5,5).

Returning to the cutter example, suppose we have defined a pose called **part_pose** that is the pose of the part model relative to the Universe. To move a cutter on a corner of the part four inches in from both sides (X = 4 inch, Y = 4 inch), we would construct the pose as follows (Figure 4-14):

```
cutter_pose:=mk_pose(4*inch, 4*inch, 0, 0, 0, 0) rel part_pose;
```

NOTE

The SIL operator **times** can also be used:

```
cutter_pose := part_pose * mk_pose(4*inch,
                                   4*inch, 0, 0, 0, 0);
```

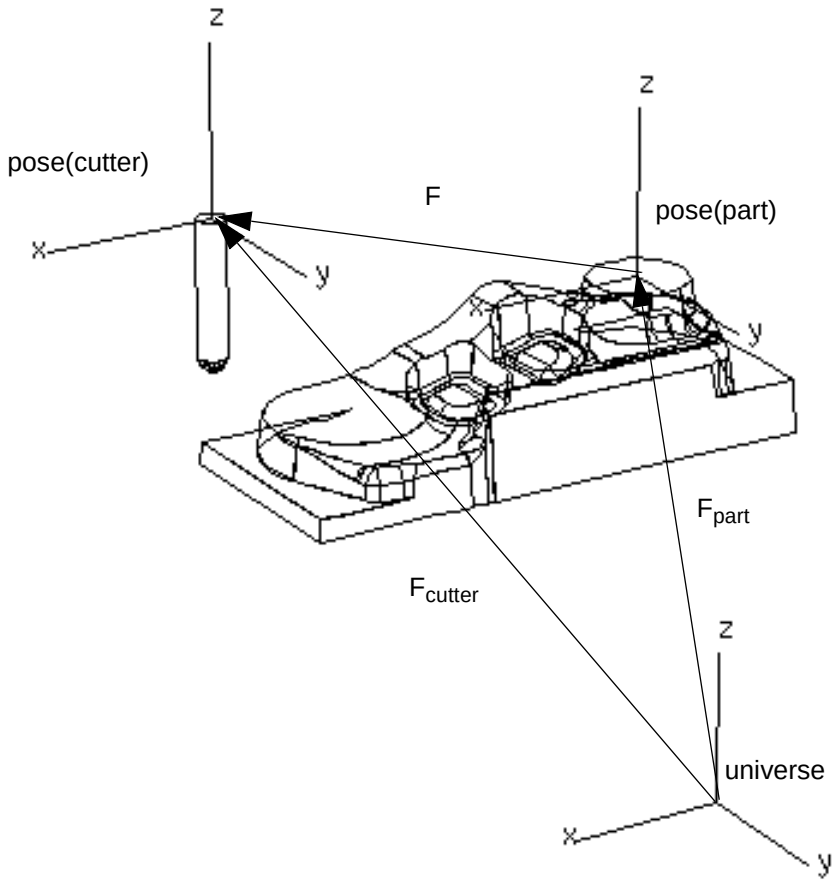
Sometimes we know the poses of two frames relative to the Universe, but would like to know the pose of one in the frame of the other. For this, we use the **in_frame** operator:

```
<geometric type>in_frame<pose>;
```

where the argument preceding **in_frame** can be any absolute position, orientation, or pose (relative to the Universe), and the argument following **in_frame** is a pose relative to the Universe. The value returned is always a position, orientation, or pose with the pose specified after the **in_frame** operator as its reference instead of the Universe. For example, consider a pose of (1,2,3,0,0,0) and a position (3,2,1). This position in the frame of the given pose would be (2,0,-2). That is,

```
mk_crt(3,2,1)in_frame mk_pose(1,2,3,0,0,0);
```

returns the absolute position (2,0,-2).



F = pose(cutter) in_frame pose(part);

F_{part} = pose(part)

F_{cutter} = pose(cutter)

= F rel F_{part}

= F_{part} * F

Figure 4-14 **in_frame** and **rel** operators

The **in_frame** operator is useful if we need to rearrange components of a simulated workcell without changing their poses relative to one another. For example, suppose we have defined a part model and cutter pose relative to the Universe such that the cutter pose describes the starting position of a part program. Suppose again we need to reposition the part model to make room for mounting fixtures, but do not want to change the cutter's starting position relative to the part model. Using **in_frame**, we may find the starting position in the frame of the part model:

```
cutter_pose_in_part := cutter_pose in_frame part_pose;
```

After we have defined the new pose of the part model relative to the Universe, the new pose of the cutter pose, relative to the Universe, is

```
new_cutter_pose := cutter_pose_in_part rel new_part_pose;
```

or

```
new_cutter_pose := new_part_pose*cutter_pose_in_part;
```

No matter where we decide to put the part, the new cutter pose relative to the Universe is always the value of **cutter_pose_in_part** relative to the new pose of the part.

The **in_frame** operator is also useful in finding the pose of an object relative to reference frames other than the Universe. Many CNC controllers allow the declaration of work coordinate systems (G codes 54 to 59). These coordinate systems are pre-set according to the layout of the part and fixtures.

Suppose the array **work_coord** contains the different work coordinates:

```
var work_coord: darray of frame;;
```

To find the pose of cutter in frame of one of the work coordinates:

```
cutter_pose_in_work_coord := pose(cutter) in_frame
                             work_coord[n];
```

where **n** denotes the work coordinates number (**n**=0 for **G54**, 1 for **G55**, etc.).

To find the Cartesian coordinates (x, y, z) of the cutter in frame of the work coordinates:

```
var crt_cutter: crt;;
crt_cutter := pos(cutter) in_frame work_coord[n];
```

The default unit in Soft Machines is always centimeter (cm). The arguments of **crt_cutter (crt_cutter.xc, crt_cutter.yc, crt_cutter.zc)** will therefore be represented in cm. To find the Cartesian coordinates in current units used (inch, mm, etc.), we do

```
crt_cutter := (pos(cutter) in_frame work_coord[n]) *
              1/current_unit;
```

where **current_unit** can be **cm**, **mm**, **inch**, **meter**, etc.

To find the yaw, pitch, roll of the cutter in frame of the work coordinates:

```
var ypr_cutter: ypr;;
ypr_cutter := (ornt(pose(cutter)) in_frame work_coord[n]): ypr;
```

where **ornt** returns the orientation (type **rotmat**) of a pose, and : **ypr** coerces the type **rotmat** (rotation matrix) to **ypr** (yaw, pitch, roll).

Example 4.3 illustrates how to move a cutter in frame of different work coordinates.

Example 4.3

Suppose the object **'VMC_REF**' defines the reference coordinate of the NC machine **'VMC**'. We add 6 sub-objects **VMC_REF/WORK_COORD_1**, **VMC_REF/WORK_COORD_2**, …, **VMC_REF/WORK_COORD_6** to define the 6 possible work coordinate systems.

These statements are used to move an object using the work coordinate systems as reference frame:

```
ref_frame ==
   pose( wlkup('VMC_REF/WORK_COORD_' *
         int2str(current_work_coord)));
```

where **current_work_coord** is one of **{1, 2, 3, 4, 5, 6}**.

continued on next page

Example 4.3 (continued)

To move the cutter '**VMC_CUTTER**' to **(XT, YT, ZT)** in frame of current working coordinates:

```
moveto(wlkup('VMC_CUTTER'),
   mk_point(XT*current_unit, YT*current_unit,
            ZT*current_unit) rel ref_frame);
```

or

```
moveto(wlkup('VMC_CUTTER'),
   ref_frame *
   mk_crt_ypr(XT*current_unit, YT*current_unit,
              ZT*current_unit, 0, 0, 0));
```

Chapter 5

Modeling Using SIL Commands

Creating models using the menus and panels is usually the most efficient way to create models. You can also, however, create models using the SIL language. The first part of this chapter describes how to create models using SIL commands. The last part of this chapter provides examples of models.

The model Data Type

All Soft Machines models, both rigid and structured, are represented internally with the same data type: **model**. The **model** data type is a data structure with fields for the following:

1. The name of the model. This name is used during a simulation to refer to the model and its components. Names are always given as strings.
2. Its kind (rigid or structured).
3. The model body.
4. The color of the body.
5. Pointers to the model's submodels (if any).

Modeling Constructors

Because Soft Machines models are represented by their boundaries (which are in turn limited to vertices, edges, and facets), you will need only a few basic constructors to build even the most complex models. For convenience, you may build more sophisticated constructors out of these basic ones. Soft Machines provides some of these more sophisticated constructors—you can create the others using the following examples as guides.

The World coordinate frame is the base coordinate system used by all the modeling constructors. For this reason, all geometric values specified in the constructors are absolute values. Most constructors

return models centered on the origin of the World coordinate frame. They may be transformed to new locations with the **moveto** and **moveby** commands.

Operator	Resulting Shape
mk_point(<xc>,<yc>,<zc>)	Cartesian point

Curves

Operator	Resulting Shape
mk_rctcurve (pts : darray of pnt3dr)	rctcurve
mk_rctcurve (pts : darray of pnt3dr; n : integer)	rctcurve
n use **[0.. n]** points as input	
mk_rctcurve (p,q : pnt3dr)	rctcurve
mk_circle (r : real)	circle
centered at origin	
mk_circle (radius : real; p : pnt3dr)	circle
p center	
mk_circle (radius : real; f : frame)	circle
f circle defined w.r.t the frame	
arc (r,a : real; res : integer)	circle
r radius	
a angle in degrees **[0..360.0]**	
res resolution	
arc (r,a : real)	circle
r radius	
a angle in degrees **[0..360.0]**	
arc (r : real)	circle
r radius	

Conics

a-x coefficients, b-y coefficients

Operator	Resulting Shape
mk_ellipse (a,b: real)	ellipse
mk_parabola (a: real)	parabola
mk_hyperbola (a,b : real)	hyperbola

Operator		Resulting Shape
mk_rbspline (knts,wghts : darray of real; cpts: darray of pnt3dr)		rbspline
knts	knots	
wghts	rational part of the point called “weights”	
cpts	control points	
mk_rbspline (knts : darray of real; cpts : darray of pnt3dr)		rbspline
knts	knots	
wghts	all weights equal to 1.0	
cpts	control points	

Operator		Resulting Shape
mk_pcurvelist(pcs : list of pcurve)		pcurvelist
mk_pcurve (p : pnt3dr)		pcurve
p	point	
mk_pcurve (p : seg3dr)		pcurve
p	line segment	

Surfaces

Cap

angle 0 to 360 degrees creates partial cap

The edge of a partial cap starts at x = <**radius**>, y = 0, sweeps counter clockwise <**angle**> degrees around the Z axis, and has an additional edge to close the polygon

resolution number of facets in cap (if omitted, **c_circ_res** is used)

Operator	Resulting Shape
mk_cap(<radius>[,<angle>]);	circular polygon
mk_cap(<radius>[,<angle>,<resolution>]);	circular polygon

Facet

The first three points establish the plane of the facet, and all points specified subsequent to them must lie in that plane. Order the points in the counterclockwise direction looking toward the facet from its outside. This establishes the direction of the facet's normal.

Operator	Resulting Shape
facet(list(<point1>,<point2>,<point3> [,...,<pointn>]));	convex planar polygon
facet(array(<point1>,,<point2>,<point3> [,...,<pointn>]));	convex planar polygon

Plane Surface

n normal

d distance to origin

sz extents

pl plane structure

Operator	Resulting Shape
mk_plsurf (n : dir3dr; d,sz : real)	plsurf
mk_plsurf (n : dir3dr; d : real)	plsurf
mk_plsurf (pl : plane)	plsurf

Grid Surface

g point grid

ng normal grid

Operator	Resulting Shape
mk_gsurface (g,ng : grid) (makes grid gsurface)	gsurface
mk_gsurface (g : grid) (makes grid gsurface for which normals are calculated automatically)	gsurface
psurf_to_gsurf (z : psurface) (generates discrete grid surface out of psurface)	gsurface

crvs1,crvs2 first, and second curve list

Operator	Resulting Shape
mk_rsurf (crvs1,crvs2 : list of pcurve)	rsurf

Be sure that pcurves are oriented correctly to avoid twisted ruled surfaces.

Surface of Revolution

crvs	generatrix curves
theta	angle revolution in rad
ax	axis of revolution

Operator	Resulting Shape
mk_rvsurf (crvs: list of pcurve; theta: real)	rvsurf
mk_rvsurf (crvs : list of pcurve)	rvsurf
mk_rvsurf (ax: seg3dr; crvs: list of pcurve; theta: real)	rvsurf
mk_rvsurf (ax : seg3dr; crvs : list of pcurve)	rvsurf

Tube as rvsurf

r	radius of tube
a	angle revolution in degrees (0 to 360)
h	height of tube
ur	resolution in circular direction (if omitted, **c_circ_res** is used)

Operator		Resulting Shape
tube	**(r,a,h: real; ur: integer)**	rvsurf
tube	**(r,a,h : real)**	rvsurf
tube	**(r,h: real)**	rvsurf

Funnel as rvsurf

r1,r2 first, and second radii of funnel

a1 angle revolution in rad

h height of tube

ur resolution in circular direction

Operator	Resulting Shape
funnel (r1,r2,a1,h : real; ur : integer)	rvsurf
funnel (r1,r2,a1,h : real)	rvsurf
funnel (r1,r2,h : real)	rvsurf

Tabulated Cylinder

endpt endpoint of generatrix

base directrix

Operator	Resulting Shape
mk_tcsurf (endpt: pnt3dr; base: list of pcurve)	tcsurf

Rational B-Spline Surface

knts1,knts2 u, v knots

cpts control points

wghts rational part of control points (weights)

Operator	Resulting Shape
mk_rbsurf (knts1,knts2,wghts: darray of real; cpts: darray of pnt3dr)	rbsurf
mk_rbsurf (knts1,knts2 : darray of real; cpts : darray of pnt3dr)	rbsurf

d1,d2	degrees in the u, v directions
fno	is a “formno” gives a simple description of what type of surface this really is, such as cylinder, sphere, etc.
coefs	coefficients of spline surf

Operator	Resulting Shape
mk_bsurf (fno,d1,d2: integer; knts1,knts2: darray of real; coefs: darray of pnt3dr)	rbsurf
mk_bsurf (d1,d2: integer; knts1,knts2 : darray of real; coefs: darray of pnt3dr	rbsurf

Coons Surface

sg1,sg2,sg3,sg4	line segment boundaries
pc1,pc2,pc3,pc4	pcurve boundaries
k	specifies the type: 0 for linear and 1 for cubic

Operator	Resulting Shape
mk_cnsurf (sg1,sg2,sg3,sg4: seg3dr; k: integer)	cnsurf
mk_cnsurf (pc1,pc2,pc3,pc4 : pcurve; k : integer)	cnsurf

The next variants for surfaces ensure that if any rectilinear curve is revolved about an axis or if any cylinder is built on a rectilinear curve, the subdivision that is generated will respect the vertices of the curve and not “round” them. Note that a **shape** is returned and not one of the surface types. The subshapes of this shape are the rectilinear (dsurface) and/or smooth (psurface) pieces of the shape. The variables **with_top** and **with_bottom** give the resultant shape a top or bottom, respectively. Note that the axis of rotation is along the Z-axis of the World coordinate system.

Operator	Resulting Shape
mk_rvsurf_shape (pc: pcurve; theta: real; with_bottom,with_top: boolean)	shape
mk_rvsurf_shape (pc: pcurve; theta: real)	shape
mk_rvsurf_shape (pc: pcurve)	shape
mk_rvsurf_shape (pcs : list of pcurve; theta : real; with_bottom,with_top : boolean)	shape
mk_rvsurf_shape (pcs : list of pcurve; theta : real)	shape
mk_rvsurf_shape (pcs : list of pcurve)	shape
mk_rvsurf_shape (ax : seg3dr; pcs : list of pcurve; theta : real; with_bottom, with_top: boolean)	shape
mk_rvsurf_shape (ax: seg3dr; pcs: list of pcurve; theta: real)	shape
mk_rvsurf_shape (ax :seg3dr; pcs : list of pcurve; with_bottom,with_top: boolean)	shape
mk_rvsurf_shape (ax: seg3dr; pcs: list of pcurve)	shape

Geometric Constructors

Conic Constructors

Let **z** be of type **conic2dr** (structure has general conic coefficients).

Let **tp** be an integer from {**hyperb_type,elips_type,parab_type**}.

NOTE	The next **mk_ellipse** and **mk_hyperbola** function below use type **conic_data = tuple_of(frame,real,real,integer).**

Operator	Resulting Shape
mk_ellipse(z,tp)	ellipse
mk_ellipse(z)	ellipse
mk_hyperbola(z,tp)	hyperbola
mk_hyperbola(z)	hyperbola
mk_parabola(z,tp)	parabola
mk_parabola(z)	parabola

Operator	Resulting Shape
mk_circular_arc (center,begpt,endpt: pnt2dr; zt: real)	circle
mk_circular_arc (center,begpt,endpt : pnt2dr)	circle

Bezier Curve Constructor

We string together Bezier curves defined by four successive points. If necessary, some points at the end are duplicated.

Operator	Resulting Shape
mk_pspline (p0,p1,p2,p3: pnt3dr)	pspline
p0 - p3 are the control points of the Bezier curve	
mk_psplines (pts: darray of pnt3dr)	pspline

Similar to **mk_psplines**, except here the resulting curve has continuous tangent vectors.

Operator	Resulting Shape
mk_pspline (pts : darray of pnt3dr; n : integer)	pspline
mk_pspline (pts : darray of pnt3dr)	pspline

Bezier Patch Constructor

Operator	Resulting Shape
mk_psurf (cpts: darray of pnt3dr)	psurf

cpts [0..15] is an array of control points for the Bezier patch.

g(u,v) = [1 u u*u u*u*u] B S Bt [1 v v*v v*v*v]t

Conic Surface Constructors

Operator	Resulting Shape
ellipsoid (a,b,c: real; sdiv: integer)	shape
ellipsoid (a,b,c : real)	shape

These functions construct the ellipsoid of “dimension” a, b, and c about origin.

Evaluating Parametric Shapes

Use the commands in this section (through page 5-14) to evaluate points, tangents and normals of parametric curves and parametric surfaces.

Parametric Curves

Given a parametric curve **pc** and a parametric variable **t**, the command for evaluating the point on the parametric curve at **t** is

pnt:= eval_at(pc, t);

where **pnt** is the point on the parametric curve **pc** at **t**.

The command for evaluating the tangent of the parametric curve at **t** is

tangt:= tangent_at(pc, t);

where **tangt** is the tangent of **pc** at **t**.

In Soft Machines, each shape has a frame known as its **seg_pose**.The **seg_pose** of a shape is the frame that locates the shape from its default location to a desired location in the workcell.

For example, the **seg_pose** of a surface of revolution is at the pose of the World when it is created. However, when the surface of revolution is moved to another location, the **seg_pose** is no longer at the pose of the World. Note that both **eval_at()** and **tangent_at()** evaluate points and tangents at the default location. Therefore, if a parametric shape is moved to a new location, and you wish to evaluate both the point and tangent with respect to this new location, use the following syntax instead:

```
pnt:= seg_pose(pc) * eval_at(pc, t);
tangt:= ornt(seg_pose(pc)) * tangent_at(pc, t);
```

Parametric Surfaces

Given a parametric surface **ps** and parametric variables **u** and **v**, the command for evaluating the point on the parametric surface at [**u,v**] is:

```
pnt:= eval_at(ps,u,v);
```

The command to evaluate the normal at [**u,v**] is:

```
nrm:= normal_at(ps, u, v);
```

Considerations regarding **seg_pose** with parametric surfaces are similar to those regarding **seg_pose** with parametric curves. The syntax to evaluate points and normals on a parametric surface **ps** in absolute World coordinates is:

```
pnt:= seg_pose(ps) * eval_at(ps, u, v);

nrm:= ornt(seg_pose(ps)) * normal_at(ps, u, v);
```

Wireframe Models

Operator	Resulting Shape
chain(list(<point1>,<point2>[,...,<pointn>]));	open chain

Volume Models

Cylinder

resolution number of facets in circumference of the cylinder (if omitted, **c_circ_res** is used)

angle between 0 and 360 creates partial cylinder

Operator	Resulting Shape
cylinder(<radius>,[<angle>,]<height>, [<resolution>]);	cylinder

Block

Operator	Resulting Shape
block(<length>,<width>,<height>);	block

Pipe

radius1 outside radius

radius inside radius

resolution number of trapezoidal prisms in the pipe (if omitted, **c_circ_res** is used)

Operator	Resulting Shape
pipe(<radius1>,<radius2>,<height> [,<resolution>]);	cylindrical volume model with inside and outside radius

Cone

resolution specifies the number of triangular facets in the circumference of the cone (if omitted, the value of the global variable **c_circ_res** is used)

Operator	Resulting Shape
cone(<radius>,<height>[,<resolution>]);	cone

Frustum

radius1 base radius

radius2 top radius

resolution specifies the number of trapezoidal facets in the circumference of the frustum (if omitted, the value of the global variable **c_circ_res** is used)

Operator	Resulting Shape
frustrum(<radius1>,<radius2>,<height> [,<resolution>]);	truncated cone

Model Operators

In addition to the model constructors, Soft Machines provides a number of functions which you may apply to models in order to change their characteristics. These functions are called **model operators**. A list of the model operators and a brief description of each follows.

The invert Operator

The **invert** operator returns a model whose facets face in the direction of their original direction. This has the effect of turning the model "inside out."

invert(<shape>);

The glue Operator

The **glue** operator is used to convert a workcell model into a rigid model.

```
glue('<model_name>');
```

where **<model_name>** is the name of a model existing in the workcell.

A workcell model may be an object tree which has several child objects. If an object tree is **glue**d, Soft Machines replaces the tree structure of the object tree with a rigid model. Therefore, you do not have access to any of the children individually once the model is **glue**d.

If the model or any of its children are parametric shapes, **glue** will remove the parametric information about these shapes. For this reason, models which have been **glue**d require less memory space, since Soft Machines keeps only the discrete information about the shapes—this significantly increases the efficiency of workcell simulation.

You can use glue for shapes which do not exist in the workcell, also:

```
glue('<name>',<shape1>[,...,<shapeN>]);
```

This version of glue returns a rigid shape **<name>** whose body is the combination of the bodies of **<shape1>** through **<shapeN>**.

IMPORTANT	DO NOT use this command if any of the shapes from **<shape1>** through **<shapeN>** exist in the workcell.

When this version of **glue** is invoked, Soft Machines defines a reference frame for the resulting shape, and places it on the shape at the same place as the World coordinate frame. This makes it seem as though an invisible copy of the World coordinate frame were included with the shape when it is **glue**d. Because a rigid shape only has one reference frame, any rigid shapes which are subsequently **glue**d lose their reference frames.

The **glue** operator makes no attempt to resolve duplicate elements of the body shape which results. Soft Machines does not **glue** models with dissimilar body types (wireframe or surface) together; the resulting **glue**d object will consist of two parts: a **glue**d surface and a **glue**d wireframe.

The moveto Operator

The **moveto** operator returns a model which is <**model**> moved to the absolute coordinates <**goal**>. <**goal**> may be either a position (orientation is unchanged), an orientation (position is unchanged), or a complete pose. Note that **moveto** does not redefine the reference frame of the returned model (the reference frame goes with the model).

moveto(<model>,<goal>);

The imoveto Operator

The **imoveto** operator is similar to **moveto**, but does not move the object along a straight line path towards the goal. **imoveto** instantaneously places the object at the goal without consuming any simulated time.

The moveby Operator

The **moveby** operator is similar to **moveto**, but the model value that **moveby** returns is **<model>** moved by the specified **<increment>**. The increment may be a position (orientation is unchanged) and orientation (position is unchanged), or a complete pose. Note that the **<increment>** specified causes an incremental move along or about the axes of the World coordinate frame, not the axes of the **<model>**'s reference frame.

moveby(<model>,<increment>);

IGES Conversions

Although you use the CAD Interfaces panel (displayed by selecting *Import/Export...* from the **Modeling** pulldown menu) for your IGES to Soft Machines or Soft Machines to IGES conversions, you can also do so using SIL language commands.

IMPORTANT	You must have the IGES interface installed in your product.

Converting IGES Files to Soft Machines Models

You may convert IGES model files to Soft Machines models with the **iges_to_model** function. The variants for this function are listed below.

There are four variants for the **iges_to_model** function:

<filename> is a string giving the pathname of the IGES file to be converted.

<model name> is a string which names the converted model**.**

<level list> is an integer list specifying the levels of the IGES file to be converted.

iges_to_model();

If you do not specify a **<filename>** in this variant, Soft Machines will prompt you for it. If you specify a **<filename>**, the converted model receives the product identification name from the globals section of the IGES file, and Soft Machines processes all IGES entity levels.

iges_to_model([<filename>]);
iges_to_model(<filename>,<model name>[,<level list>]);

This variant specifies a level list which will be the only level converted. Specifying a level list prevents Soft Machines from converting all levels. Soft Machines will return the **model value** type.

iges_to_model(<filename>,<model name>);

This variant reads all entities and converts all levels.

Converting Soft Machines Models to IGES files

In order to convert a Soft Machines model to an IGES file, the model you wish to convert must be in the Soft Machines product that you are using. If it is not already there, you can bring it into the product with the following function:

restore(<filename>);

where the **<filename>** must be a string. Note that **restore** is a function which returns the value of the model, so it must be assigned a model variable type in order to make use of the returned model.

The command to convert a model to an IGES file is:

model_to_iges(<model>[,<filename>]);

where **<model>** is the variable containing the value of the model to be converted. If you do not specify a **<filename>**, Soft Machines will prompt you for it during the conversion routine.

After you enter the **model_to_iges** command, Soft Machines displays a list of IGES global default parameter values, and asks you if any are to be changed. If you answer **yes**, the program steps through these parameters one at a time and asks for changes. If you answer **no**, Soft Machines prompts you for the name of an IGES file, and converts the model, writing to this file.

Modeling Examples

The following examples illustrate the use of some of the models constructors described above and demonstrate several useful modeling concepts. You are not limited to using SIL commands to create these examples—all of these models could haven been built using the panels.

Example 5.1 Link

The code to create link 1 of the Adept robot is shown below. One way to model this link is to create surfaces of the top and bottom faces and another of the perimeter. You may combine these three surfaces to create a volume model.

To begin, the points which are the vertices of the individual facets between the rounded ends of the link are:

```
p1==mk_point(0,radius1,0);
p2==mk_point(0,-radius1,0);
p3==mk_point(side_length,-radius2,0);
p4==mk_point(side_length,radius2,0);
p5==mk_point(0,radius1,height);
p6==mk_point(0,-radius1,height);
p7==mk_point(side_length,-radius2,height);
p8==mk_point(side_length,radius2,height);
```

The interior of the bottom surface is:

```
interior==facet(list(p1,p2,p3,p4));
```

The rounded ends of this surface are:

```
end1_cap==moveto(mk_cap(radius1,180),mk_ypr(0,0,90));
end2_cap==moveto(mk_cap(radius2,180),
mk_pose(side_length,0,0,0,0,-90));
```

A face is made up of these three surfaces:

```
face1==glue(interior,end1_cap,end2_cap);
face2==copy(face1);
```

(continued on next page)

Example 5.1 Link (continued)

Now you may use this face to create the top and bottom faces of the link by inverting it (bottom) and translating it (top).

```
top_face==moveto(face2,mk_crt(0,0,height));
bottom_face==invert(face1);
```

The rounded facets for the outside surface are

```
end1_surf==moveto(tube(radius1,180,height), mk_ypr(0,0,90));
end2_surf==moveto(tube(radius2,180,height),
mk_pose(side_length,0,0,0,0,-90));
```

The front and back facets between these two ends are

```
front==facet(list(p5,p8,p4,p1));
back==facet(list(p3,p7,p6,p2));
```

The perimeter is

```
perimeter==glue(front,back,end1_surf,end2_surf);
```

Finally, link 1 is

```
link1_body==glue(top_face,bottom_face,perimeter);
add('link1',link1_body);
```

Example 5.2 Open Box

The **block** constructor creates a model of a block. A constructor for an open box could be written as follows:

```
function openbox(x,y,z:real):shape;
var pt1,pt2,pt3,pt4,pt5,pt6,pt7,pt8: point;
    bottom,left,right,front,back,outside,inside: shape;
begin
    pt1:=mk_point(0,0,0);
    pt2:=mk_point(x,0,0);
    pt3:=mk_point(x,y,0);
    pt4:=mk_point(0,y,0);
    pt5:=mk_point(0,0,z);
    pt6:=mk_point(x,0,z);
    pt7:=mk_point(x,y,z);
    pt8:=mk_point(0,y,z);
    bottom:=facet(list(pt4,pt3,pt2,pt1));
    left:=facet(list(pt1,pt2,pt6,pt5));
    right:=facet(list(pt3,pt4,pt8,pt7));
    front:=facet(list(pt2,pt3,pt7,pt6));
    back:=facet(list(pt4,pt1,pt5,pt8));
    outside:=glue(bottom,left,right,front,back);
    inside:=copy(outside);
    inside:=invert(inside);
    openbox:=glue(outside,inside);
end;
```

The parameters **<x>**, **<y>**, **<z>** define the length, width, and height of the box respectively, and it is open at the top. Note that the box has both an inside and outside so that it can be viewed from the inside.

For example, if you wished to create an open box with dimensions of [5, 5, 5], you would use the following:

```
box==openbox(5,5,5);
add('openbox',box);
```

Example 5.3 Grid Surface

The following creates a grid surface.

```
procedure hercules();
var gr: grid;
      nrows: integer;
      ncols: integer;
      j: integer;
      temp:real;
      parent_shp: shape;
      comp_shp: gsurface;
      comp_shp2: gsurface;
begin
      nrows:=6;
      ncols:= 17;
      gr:= mk_grid(nrows, ncols);
      for j:= 0 to 16 do
      begin
          temp:= float(j);
          gr[0,j]:= mk_point(0.0, 2.25*temp, 9.0) * inch;
          gr[1,j]:= mk_point(7.395, 2.25*temp, 9.0) *inch;
          gr[2,j]:= mk_point (9.0,2.25*temp,7.395)*inch;
          gr[3,j]:= mk_point(9.0,2.25*temp,-7.395)*inch;
          gr[4,j]:= mk_point(7.395, 2.25*temp, -9.0) *inch;
          gr[5,j]:= mk_point(0.0, 2.25*temp, -9.0)*inch;
      end;
      comp_shp:= mk_gsurface (gr);
      comp_shp2:= mk_gsurface(gr);
      moveto(comp_shp2, mk_ypr(0,0,180.0));
      moveto(comp_shp2, mk_point(0,36.00*inch,0.0));
      parent_shp:= mk_empty_shape();
      add('hercules',parent_shp);
      add('side1',comp_shp);
      adopt('hercules', 'side1');
      add('side2', comp_shp2);
      adopt('hercules','side2');
end;
```

Example 5.4 Hollow Cylinder

The following creates a hollow cylinder using **mk_rsurf** (ruled surface).

```
function hollow_cyl(radius, height: real): shape;
var circle1, circle2: pcurve;
   outside, inside: shape;
begin
     circle1:= circle(radius) as_type pcurve;
     circle2:= circle(radius) as_type pcurve;
     moveto(circle2, mk_crt(0,0,height));
     {Create a ruled surface}
     outside:= mk_rsurf(list(circle1), list(circle2));
     inside:= copy(outside);
     inside:= invert(inside);
       { By calling glue, the parametric informations of the ruled
         surface is destroyed. }
     hollow_cyl:= glue(outside, inside);
end;
```

To create a hollow cylinder into the workcell:

```
temp== hollow_cyl(<radius>, <height>);
add('<name>', temp);
```

Example 5.5 Sphere

The following creates a sphere using **mk_rvsurf** (surface of revolution):

```
function sphere(radius: real): shape;
var arc_shp: pcurve;
begin
     arc_shp:= arc(radius, 180.0) as_type pcurve;
     moveto(arc_shp, mk_ypr(0.0,90.0,0.0));
     sphere:= mk_rvsurf(list(arc_shp));
end;
```

To create a sphere in the workcell:

```
temp== sphere(<radius>);
add('<name>',temp);
```

Example 5.6 Bottle Shape

The following creates a bottle shape using **mk_rsurf** and **mk_rvsurf**.

```
cir1==circle(1.0) as_type pcurve;
cir2==circle(1.0) as_type pcurve;
moveto(cir1, mk_crt(0.0,0.0,11.0));
moveto(cir2, mk_crt(0.0,0.0,10.0));

ruled_surf1== mk_rsurf(list(cir2), list(cir1));

cir3 == circle(3.0) as_type pcurve;
moveto(cir3, mk_crt(0.0, 0.0, 7.0));

ruled_surf2 == mk_rsurf(list(cir3), list(cir2));

pt1== mk_point(0.0,0.0,0.0);
pt2== mk_point(0.0,3.0,0.0);
pt3== mk_point(0.0,3.0,7.0);

ary== mk_array(pt1, pt2, pt3);
pcrv== mk_rctcurve(ary) as_type pcurve;

revsurf== mk_rvsurf(list(pcrv));

bottle == mk_empty_shape();
add('bottle',bottle);

name(ruled_surf1,'neck');
name(ruled_surf2,'shoulder');
name(revsurf,'body');
add_below(ruled_surf1, bottle);
add_below(ruled_surf2, bottle);
add_below(revsurf, bottle);

paint('bottle', green);
```

Chapter 6

Modeling NC Machines

This chapter contains the following topics:

- *General Overview of Soft Machines*
  - NC Simulator
  - Developing an NC Simulator
- *NC Machine Data Class*
- *Defining NC Coordinate Systems*
  - Axes Convention
  - NC Coordinates Versus SILSPEC Coordinates
  - Defining NC Reference Coordinates
  - NC Coordinates in Joint Space
  - Determining Simulation Strategy
- *Attaching a Tool Library to an NC Machine*
- *Machine Status*
- *G and M Tables*
- *Machine Pendant Panel*

The preceding chapters introduced the components needed to develop an application package using software tools included in Soft Machines. In particular, we have discussed how to use the SIL language to

- Model devices and attach special characteristics to pre-defined objects based on classes and inheritance
- Develop “tasks” for simulation
- Describe geometries of workcell objects and perform geometric operations on them.

In the following chapters, these concepts will be used to develop custom applications in the modeling and simulation of NC machine tools.

General Overview of Soft Machines

Soft Machines is a software simulator of NC machining processes using 3D graphics animation. The simulation is used for verification of NC part programs, insuring that such programs result in the intended, error-free machining processes using the specified machine tools.

The basic functionalities of Soft Machines are

- ➢ Geometrical modelling of workcell components, including part geometry, cutting tools, fixtures, etc.
- ➢ Kinematics modelling of machine tools, which allows the simulated machines to operate just like real machines
- ➢ Capability to load, interpret and execute NC part programs by the simulated machine tool
- ➢ Graphical user interface
- ➢ Reporting of simulation results

Figure 6-1 on page 6-3 shows the data flow diagram for Soft Machines.

NC Simulator

An **NC simulator** can be considered as a set of software modules through which NC part program's (G and M codes) statements are translated into commands for a simulated machine-tool. An NC machine can be modeled by attaching the simulated controller to the kinematics model of a machine-tool (**SILSPEC**).

An NC simulator contains the following components:

- ■ A part program translator (G code translator) translating part program statements into Soft Machines commands. This can either be a generic translator handling simple syntax, or a custom module written specifically for a particular machine model.

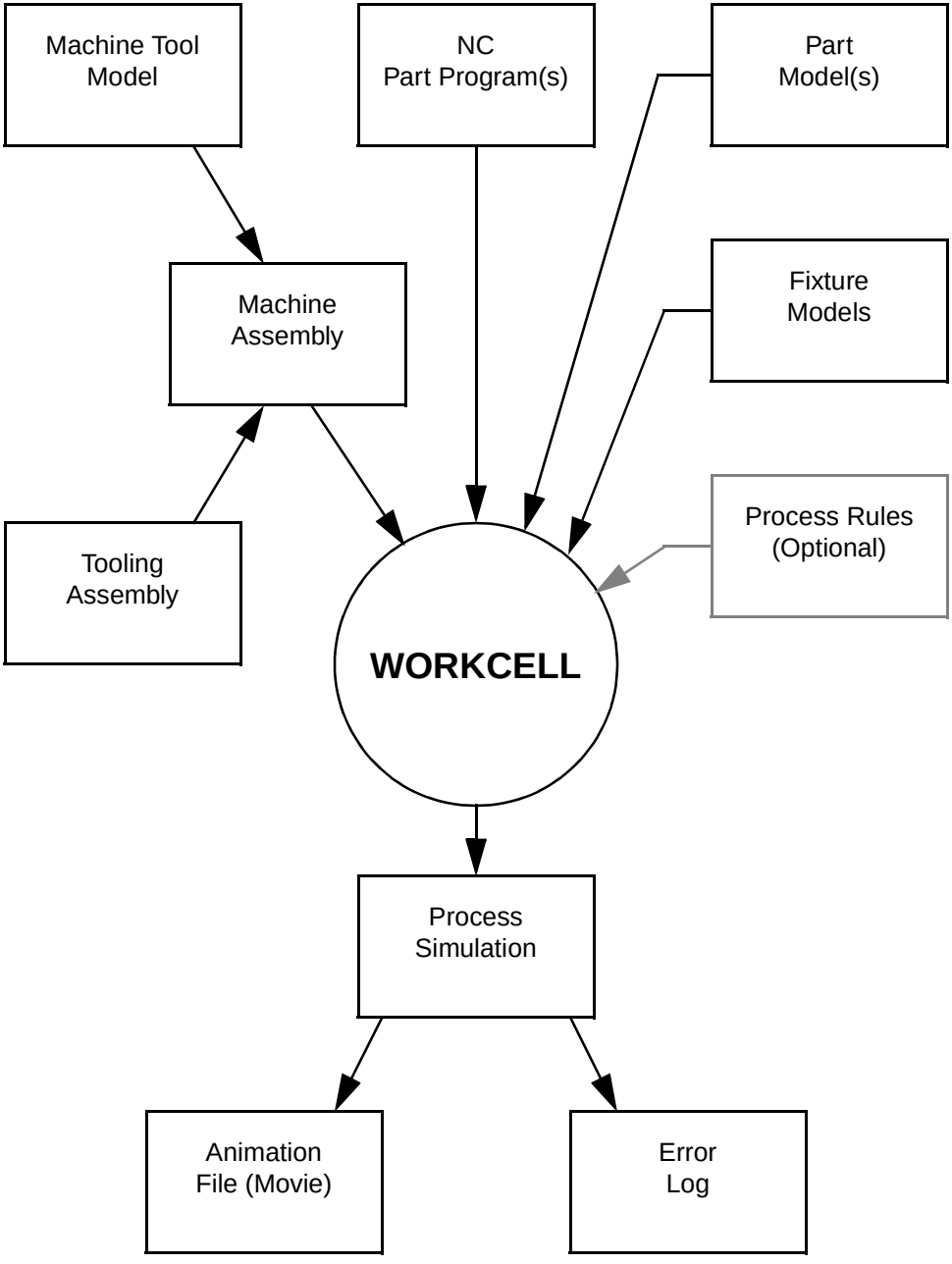


Figure 6-1 Data flow diagram for Soft Machines

- Arrays of SIL task closures (called G and M tables) connecting G and M code commands to Soft Machines commands.
- User menus allowing control of the machine model using mouse-menu interface.
- Other parameters, such as machine reference coordinates, status of machine (coolant, spindle, …), interface to external tool databases, etc.

Table 6-1 shows how software modules providing these capabilities can be summarized.

FUNCTIONALITY	SOFTWARE MODULE
Workcell modeling	Base Soft Machines
Model tooling	NC tooling modeler
Kinematics modeling of NC machines	SILMA Meta-Kinematics™ + Specialization of robot models (**SILSPEC**s)
Load, interpret and execute NC part programs	G code translator + G and M tables
Graphics user interface	NCV user menus
Reporting of simulation results	Movie shower (cine) Special error report routines

Table 6-1 Software module capabilities

Developing an NC Simulator

The development of an NC simulator can be summarized in the following steps:

1. Construct kinematics model of machine (**SILSPEC**) using SILMA Metakinematics.
2. Define machine parameters such as reference frames.

3. Develop machine specific routines (SIL procedures, functions and tasks), such as tool changes, interface to tooling database, etc.
4. Construct machine specific “machine pendant” panel for manual control of machine model using Soft Machines menus.
5. Construct G and M tables to connect G and M codes to equivalent SIL tasks.
6. Construct G code translator to translate part programs into SIL function calls.
7. Incorporate all of the above into the data class **nc_machine**.

Figure 6-2 on page 6-6 gives a schematic overview of the software architecture in Soft Machines.

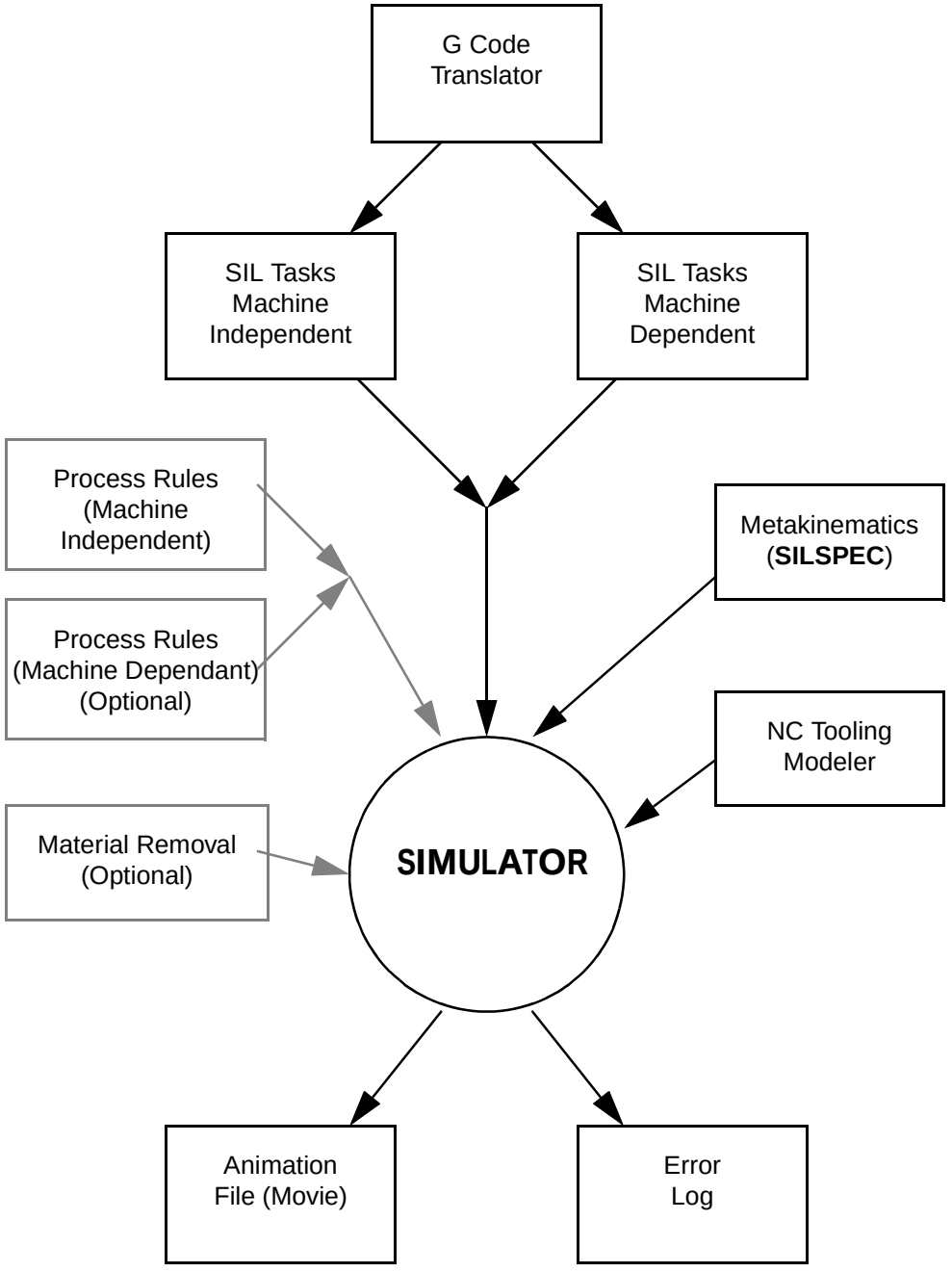


Figure 6-2 Software modules for NC simulator

NC Machine Data Class

As discussed in previous chapters, an NC machine is considered a subclass (specialization) of **robot**. "Using Closures and tclosures to Customize G Code Translators" on page 2-47 explained how to attach a G code translator and two arrays of **tclosure**s (G and M tables) to an NC machine by inserting the fields **translator**, **gtable** and **mtable** to the type **nc_machine**. The complete type declaration for **nc_machine** is

```
new_class(nc_machine,                    { NC machine - subclass of robot }
superclass: generalize: robot,
x_axis: string,                          { Names of objects denoting machine axes }
y_axis: string,                          { Null strings for non-existent axes }
z_axis: string,
a_axis: string,
b_axis: string,
c_axis: string,
x_link: integer,                         { SILSPEC links corresponding to machine axes }
y_link: integer,
z_link: integer,
a_link: integer,
b_link: integer,
c_link: integer,
changer_mount: string,                   { Mount flange for tool changer }
changer_link: integer,
tlib: string,                            { Tool library associated with machine }
station_no: integer,                     { Current tool station no }
ref: string,                             { Object defining machine reference frame }
base_frame: frame,                       { Base reference frame during initial power-up }
base_jv: jv,                             { Join vector of machine at base frame }
move_handle: string,                     { Move handle for machine end effector }
pendant: mnode,                          { Machine pendant panel }
monitor: mnode,                          { Machine monitor panel }
status: machine_status,                  { Machine status }
```

```
gtable: array_of(g_function),        { G code table }
mtable: array_of(gcode_closure),     { M code table }
translator: gc_translator,           { G code translator }
rules: list_of(gc_rules));;          { Machining rules }
```

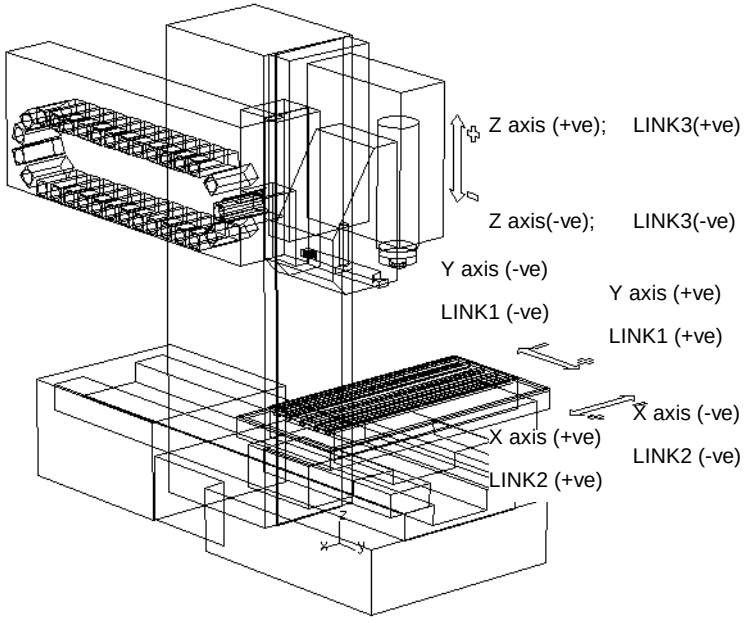
Defining NC Coordinate Systems

Axes Convention

The fields **x_axis**, **y_axis**, **z_axis**, **a_axis**, **b_axis**, **c_axis** (type **string**), **x_link**, **y_link**, **z_link**, **a_link**, **b_link**, **c_link** (type **integer**) map the machine axes to robot joint vectors (JV) in Soft Machines. An example of a 3-axis vertical machining center VMC is shown in Figure 6-3. This is necessary because kinematics models (**SILSPEC**s) created by SILMA Meta-Kinematics follow common robotics conventions (for example, in robotics, the term *link* is used instead of *axis*).

Specifically, the fields **{x,y,z,a,b,c}_axes** contain the names of the shapes corresponding to the X, Y, Z, A, B and C axes respectively. In Figure 6-3, the object corresponding to the X axis of the machine is **'LINK2'**, so the field **vmc.x_axis** contains the string '**LINK2**'. Since '**LINK2**' is a child (descendant) of the machine model, its full path name is '**VMC/LINK2**', or, **concat(name(vmc), '/', vmc.x_axis)**. To affix a model named '**fixture**' to the X axis of the machine, you would use the SIL statement:

```
affix('fixture', concat(name(vmc),'/',vmc.x_axis));
```



vmc.x_axis = 'LINK2' vmc.x_link = 2
vmc.y_axis = 'LINK1' vmc.y_link = 1
vmc.z_link = 'LINK3' vmc.z_link = 3

Figure 6-3 Mapping NC axes to joint links

The fields **{x,y,z,a,b,c}_link** contain the link number of the respective axes. The sign of each field tells the direction of the axis with respect to the direction of the joint vector: +ve sign means the machine axis and the **SILSPEC** link moves in the same direction; -ve sign means they move in opposite direction. In Figure 6-3, **x_link** is +2. If you wanted to move the X axis of **VMC** by the distance **x_incr**, you would use

```
moveby(vmc, vmc.x_link, x_incr);
```

A more general case would be

```
moveby(vmc, vmc.x_link, sgn(vmc.x_link)*x_incr);
```

where **sgn(vmc.x_link)** gives the direction of motion with respect to the link.

Machines with fewer than 6 axes contain null fields for non-existent axes: **null_string** for **{x,y,z,...}_axes**, and the global **ncv_null_link** for **{x,y,z,...}_link**.

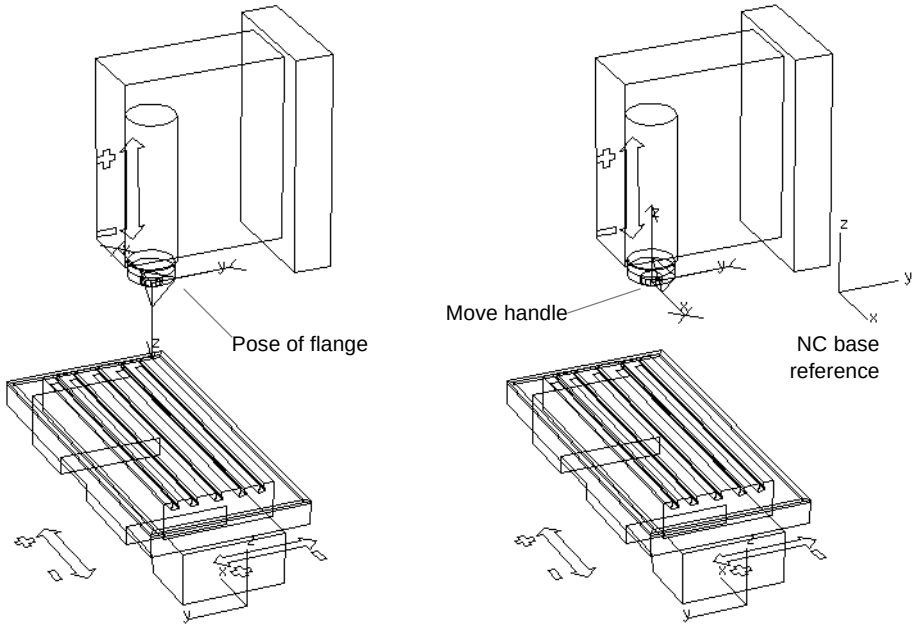
NC Coordinates Versus SILSPEC Coordinates

Just as we want to map the axes of an NC machine to the links of a **SILSPEC**, the NC coordinates need to be mapped with respect to the coordinates of the **SILSPEC**'s '**flange**'. The **flange** is where an end effector (tool) is mounted onto a **SILSPEC**. For an NC machine, the flange is usually the spindle flange where a tool holder is mounted.

It is common in robotics to define the Z axis of the flange as pointing away from the *machine*. In contrast, the Z axis of an NC machine usually points away from the *part*. This problem is solved by defining an empty shape (an object that has a pose only) called the **move_handle**. By aligning the pose of the **move_handle** with the NC coordinates and affixing it to the flange of the **SILSPEC**, the **move_handle** provides the coordinate reference with which the machine can move (see Figure 6-4).

The name of **move_handle** can then be inserted into the **move_handle** field of class **nc_machine**. To move the machine VMC by **{x, y, z}** in the NC coordinate system, use

```
moveto(vmc.move_handle, mk_point(x,y,z) in_frame
        pose(vmc.move_handle));
```




```
pose(vmc.move_handle) :=
mk_crt_ypr(0,0,0,-180.,0.,-180.) in_frame pose(vmc_flange);
```

Figure 6-4 Defining NC coordinates

Defining NC Reference Coordinates

NC reference coordinates can be defined in a similar manner as the **move_handle**. An empty shape, **ref**, can be constructed and moved to the pose where the reference frame is located. It is then affixed to the machine (or one of its subparts, depending on the kinematics), as shown in Figure 6-4. The field **ref** in class **nc_machine** contains the name of the reference shape.

To move the machine **vmc** to **{x,y,z}** in the NC coordinate frame:

```
moveto(vmc.move_handle, mk_crt(x,y,z) in_frame
        pose(vmc.ref));
```

or

```
moveto(vmc.move_handle,
        pose(vmc.ref)*mk_crt_ypr(x,y,z,0,0,0));
```

To change the NC reference to a new location, we can simply unaffix the reference shape from the machine and move it to a new location.

Example 6.1

Suppose the **move_handle** for machine **m** has the coordinates **{x,y,z}** relative to the new reference frame. The new reference location can be defined as follows:

```
unaffix(m.ref, name(m));
imoveto(m.ref, mk_crt(x,y,z) rel pose(m.move_handle));
affix(m.ref, name(m));
```

NOTE In this case, the reference shape is affixed to the machine (i.e., the base of the NC machine). In some cases, such as those for milling machines, it may be affixed to table of the machine which is one of the links in the **SILSPEC**. **imoveto** means internal **moveto**, and does not consume any simulated time (changing coordinate system in a machining operation does not take any real time).

Many machine controllers let us define more than one reference frames. For example, 6 part coordinates (**G54** to **G59**) can be declared. We handle this by creating 6 empty shapes and adopt them as subparts for the reference shape. When a part program calls out for a difference part coordinates, we change the **ref** field to the name of the new reference shape.

For an NC machine **m** with part coordinates defined by the subparts **WORK_COORD_1**, **WORK_COORD_2**, …, **WORK_COORD_6** of the reference shape, we change work coordinates by:

```
m.ref := concat(name(m), '/MCS/WORK_COORD_', int2str(i));
```

where **i = 1, 2, 3, …, 6**

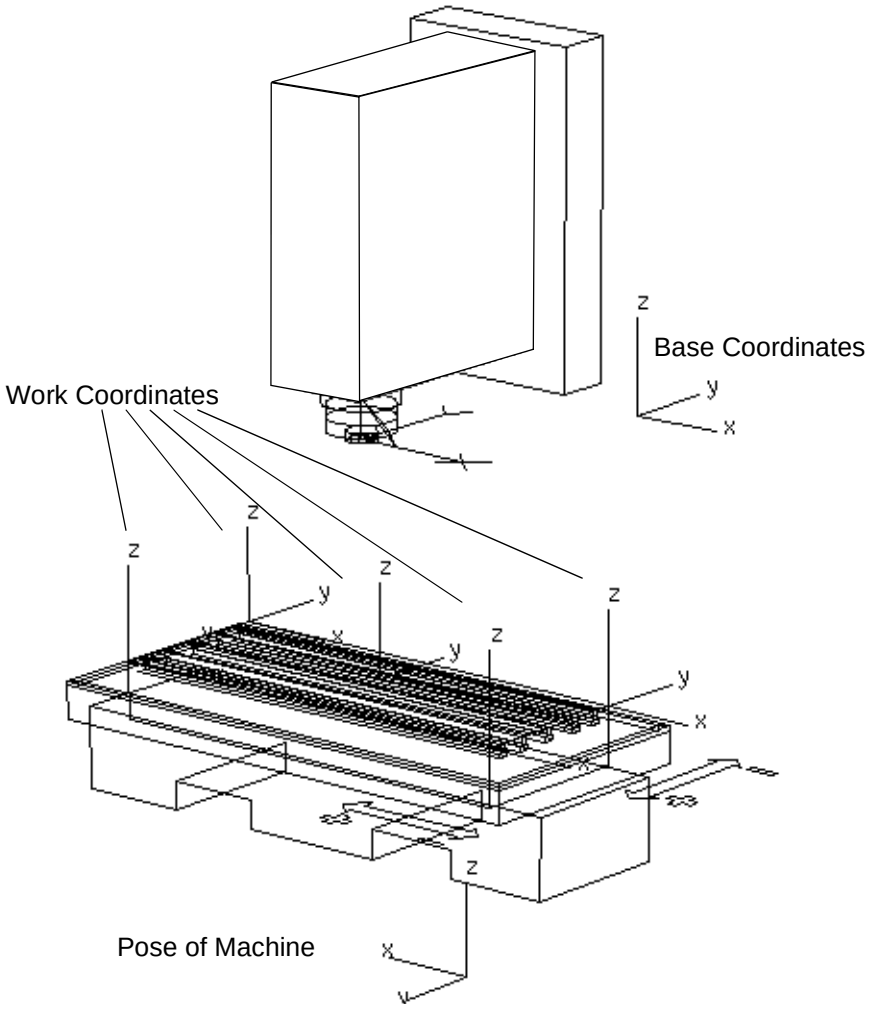


Figure 6-5 Defining multiple work coordinates

The field **base_frame** (type **frame**) contains the location of the machine reference coordinates ("power up" reference). It is equivalent to the base machine coordinates (**G53**), which are fixed, as opposed to part coordinates, which can be changed during the course of a part program. **base_frame** contains the pose of the base coordinates in frame of the pose of the machine.

The base **base_jv** (type **jv**) is the joint vector value when the machine is first initialized. Normally, **base_jv** contains the joint vector when the machine is at the home position, or (for machine **m**):

```
m.base_jv := home_of(name(m));
```

NC Coordinates in Joint Space

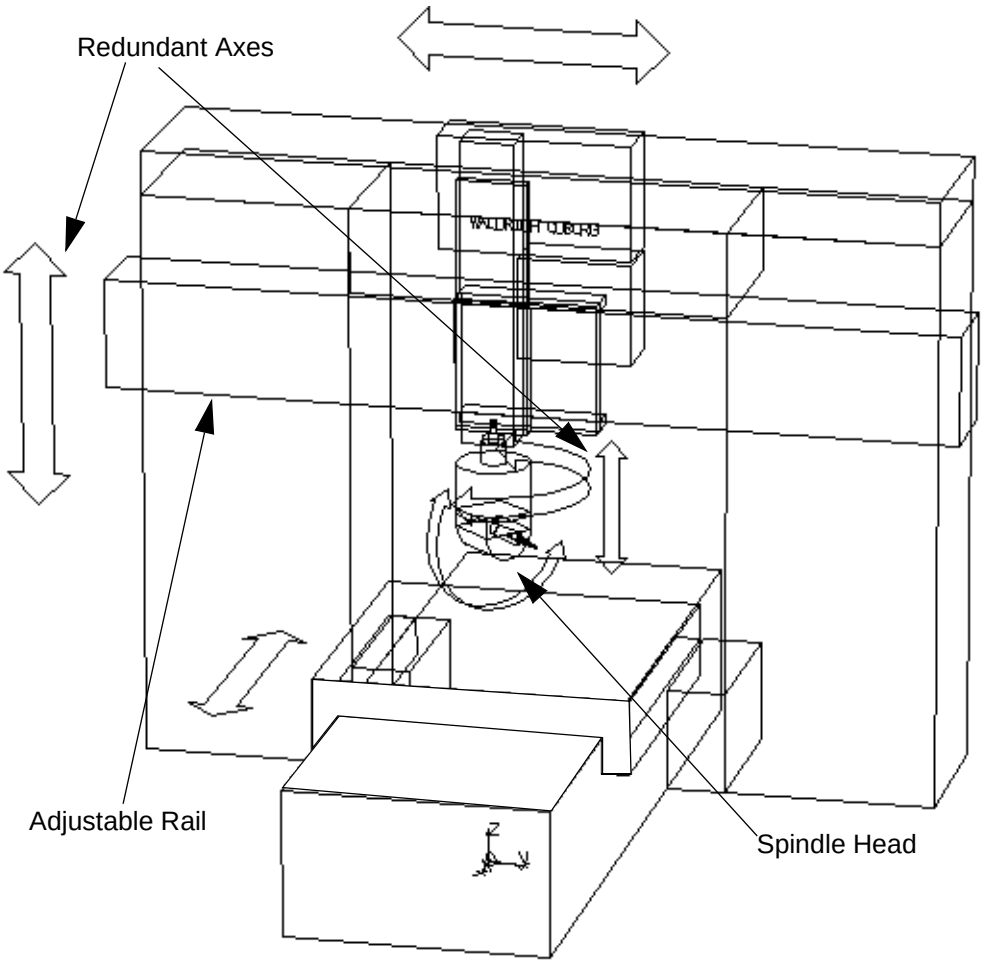


Figure 6-6 6-axis adjustable rail milling machine

We have discussed how to define machine coordinates and reference frames by affixing empty shapes to the flange and machine respectively. With this approach, we are moving the machine's end effector to a location specified by the G code part program. This kind of motion is known as **inverse kinematics motion**—the motion of each axis to effect the end effector move is computed by inverse kinematics transformations.

Inverse kinematics provides a convenient means of simulating the tool path without having to consider the machine configurations. It is applicable when a machine tool has "closed form" inverse kinematics; that is, an exact mathematical solution exists for the joint/axis motions to execute an end effector move. Typical cases where inverse kinematics apply are: 3 and 4 axis machining centers; and 2 axis lathes or turning machines.

The 6-axis "adjustable rail milling machine" shown in Figure 6-6, however, contains "redundant" axes where no exact mathematical solution exists for any inverse kinematics move - there are infinite solutions to position the adjustable rail and the spindle head to achieve the same end effector location.

To simulate machine tools with redundant geometry, Soft Machines converts a G code move command into a joint vector and then move the machine to the specified joint location. This is known as **forward kinematics** move - we are moving the *joint vectors* instead of the *end effector*.

Example 6.2 shows the SIL code to convert x, y, z, a, b, c from G code statements to machine joint vectors by utilizing the fields **x_link, y_link, …, c_link** in the class **nc_machine**.

Example 6.2

Parameters: **m** machine to move
x,y,z,a,b,c: parameters in G code statement
Returns machine joint vector

```
function nc_axes_to_jv(m: nc_machine;
                       x,y,z,a,b,c:real): jv;
var axes: darray of real;
   j: integer;
   jk: joint_kinds;
begin
   axes := array(0.,0.,0.,0.,0.,0.);
   jk := revolute(m);      { Grab revolute joints of SILSPEC }

   if (m.x_link > ncv_null_link) then
   begin
      if jk[abs(m.x_link)] then
         axes[abs(m.x_link)] := sgn(m.x_link)*x
      else
         axes[abs(m.x_link)] := sgn(m.x_link)*x*current_unit;
   end;

   if (m.y_link > ncv_null_link) then
   begin
      if jk[abs(m.y_link)] then
         axes[abs(m.y_link)] := sgn(m.y_link)*y
      else
         axes[abs(m.y_link)] := sgn(m.y_link)*y*current_unit;
   end;

   if (m.z_link > ncv_null_link) then
   begin
      if jk[abs(m.z_link)] then
         axes[abs(m.z_link)] := sgn(m.z_link)*z
      else
         axes[abs(m.z_link)] := sgn(m.z_link)*z*current_unit;
   end;
```

continued on next page

Example 6.2 (continued)

```
    if (m.a_link > ncv_null_link) then
    begin
       if jk[abs(m.a_link)] then
            axes[abs(m.a_link)] := sgn(m.a_link)*a
       else
            axes[abs(m.a_link)] := sgn(m.a_link)*a*current_unit;
    end;

    if (m.b_link > ncv_null_link) then
    begin
       if jk[abs(m.b_link)] then
            axes[abs(m.b_link)] := sgn(m.b_link)*b
       else
            axes[abs(m.b_link)] := sgn(m.b_link)*b*current_unit;
    end;

    if (m.c_link > ncv_null_link) then
    begin
       if jk[abs(m.c_link)] then
            axes[abs(m.c_link)] := sgn(m.c_link)*c
       else
            axes[abs(m.c_link)] := sgn(m.c_link)*c*current_unit;
    end;

  nc_axes_to_jv :=
          mk_jv(axes[1],axes[2],axes[3],axes[4],axes[5],axes[6]);
  end;
```

Forward kinematics moves require that all reference and work coordinates be defined in joint space as well. Recall that the field **base_jv** defines the machine reference coordinates. To execute a 6-axis forward kinematics move in machine coordinates, this expression is used:

```
moveto(m, nc_axes_to_jv(m,x,y,z,a,b,c)+m.base_jv);
```

To add work coordinates definition, we create a subclass of **nc_machine** called **machining_center**:

```
new_class (machining_center,
           superclass: generalize: nc_machine,
           ref_jv: array_of(jv),
           aux: universal);
```

in which the field **ref_jv** (type **array of jv**) contains work coordinates defined in joint vectors.

To execute a 6-axis move using work coordinates, we can do

```
moveto(mc, nc_axes_to_jv(mc,x,y,z,a,b,c)+mc.ref_jv[i]);
```

where **mc** is of class **machining_center** and **i** defines the work coordinates to use.

Determining Simulation Strategy

Although inverse kinematics provide a more straight-forward way to implement the NC simulator, forward kinematics moves are required when

- The machine does not have close-form inverse kinematics (no redundant axes)
- The work coordinates and reference coordinates cannot be represented as poses in Soft Machines

Attaching a Tool Library to an NC Machine

Before a machine tool can perform any machining operations, tooling is first mounted to the machine. In Soft Machines, NC tooling (tool changers, tool holders and cutters) are modeled and saved as **tool libraries**. When part programs are loaded for simulation, the appropriate tool libraries must be installed into the workcell and attached to the machine tool model.

The location where the tool library is affixed to the machine model is defined in the **changer_mount** (type **string**) field of **nc_machine**. When a tool library is installed, Soft Machines automatically moves it to the *pose* of the object declared in **nc.changer_mount** and also affixes the tool library to it. The name of the tool library is then attached to the **tlib** field. When the tool library is mounted to one of the links of the machine, as in the case of rotating turrets for lathes, the link number is also declared in the **changer_link** field.

The field **station_no** allows tool change routines to update the tool changer station number after a tool change has been executed. Developing SIL tasks to perform tool changes will be explained in the following chapters.

Machine Status

In order to monitor the status of a machine during simulation, the object class **nc_machine** includes the field status (type **machine_status**) which is being updated as simulation progresses. Type declaration for **machine_status** is as follows:

```
type machine_status = lrecord
   current_gcode: darray of integer;
   current_mcode: list of integer;
   current_state: string;
   programming: string;
   interpolation: string;
   spindle: string;
   coolant: boolean;
   clamp: boolean;
   unit: string;
   feed: string;
   feed_override: real;
end;;
```

FIELD	TYPE	DESCRIPTION
current_gcode	**darray of integer**	Active G codes.
current_mcode	**list of integer**	Active M codes.
current_state	**string**	State of machine: **idle** or **running**.
programming	**string**	Programming mode: **absolute** or **incremental**.
interpolation	**string**	Interpolation: **linear**, **arc cw**, **arc ccw**.
spindle	**string**	Spindle status: **off**, **cw**, **ccw**.
coolant	**boolean**	Coolant status: **TRUE** (on) or **FALSE** (off).
clamp	**boolean**	Clamp status: **TRUE** (clamp) or **FALSE** (unclamp).
units	**string**	Units used: **inch** or **metric**.
feed	**string**	Feed specification in F parameter: **linear**, **spindle**, **surface**, **rpm**.
feed_override	**real**	Feed override: 0 to 1.

Table 6-2 **machine_status** field descriptions

G and M Tables

The fields **gtable** (type **array** of **g_function**) and **mtable** (type **array** of **gcode_closure**) are arrays of task closures linking G and M codes to SIL tasks.

Similarly, the field **translator** is a closure pointing to the G code translator attached to the machine model.

REMINDER	"Closures and tclosures" on page 2-42 provides a detailed description.

Machine Pendant Panel

A customized machine pendant panel is attached to the **pendant** (type **mnode**) field of **nc_machine**. After a machine pendant panel has been constructed, it can be inserted to the **nc_machine** object class by using

vmc.pendant := vmc_ncv$pendant; (for machine VMC)

where **vmc_ncv** is the ncv support module for machine VMC.

NOTE	For information on creating panels and customizing the menu interface, contact SILMA.

Summary

The sequence for constructing an NC machine can be summarized as follows:

1. Construct kinematics model of machine (SILSPEC) with SILMA Meta-Kinematics.
2. Define machine parameters such as reference (base) and working coordinates.
3. Determine simulation strategy (forward versus inverse kinematics).
4. Develop machine specific tasks and routines, such as tool changes, interface to external tooling database, etc.
5. Construct G and M tables by combining machine dependent and machine independent tasks.
6. Construct a special machine pendant panel.
7. Construct SIL object **nc_machine**.

An example of constructing the **nc_machine** object class is shown in Example 6.3.

Example 6.3

```
{ 3 axis Vertical Machining Center }

{ Pose of handles relative to flange }
   vmc_handle_rel_flange ==
                                  mk_crt_ypr(0., 0., 0, -180., 0., 180.);

{ Pose of ref frame relative to pose of LINK2 }
   vmc_ref_rel_link ==
                           mk_crt_ypr(-150., -18.34, -38.1, -180., 90., 0.);
```

continued on next page

Example 6.3 (continued)

{ Function to construct **move_handle** }

```
function mk_vmc_handle(): shape;
var   handle, bot_flange: shape;
      handle_name: string;
begin
   handle_name := name(vmc_30_robot_model)*'_HANDLE';
   if not(object_exists(handle_name)) then
      begin
         handle := mk_empty_shape();
         add(handle, handle_name);
         bot_flange :=
         wlkup(name(vmc_30_robot_model)*'_FLANGE');
         imoveto(handle, vmc_handle_rel_flange rel
                  pose(bot_flange));
         affix(handle, bot_flange);
         mk_vmc_handle := handle;
      end
   else
      mk_vmc_handle := wlkup(handle_name);
end;
```

{ Initiate machine coordinate systems G54 - G59 }

```
function mk_vmc_mcs(): shape;
var   bot_link, mcs: shape;
      mcs_name: string;
begin
   mcs_name := name(vmc_30_robot_model)*'_MCS';
   if not(object_exists(mcs_name)) then
      begin
         mcs := mk_empty_shape();
         add(mcs, mcs_name);
         add_work_coordinates(mcs_name, 6);
                                   { Add work coord }
         bot_link := wlkup(name(vmc_30_robot_model)*
                        '/LINK2');
         imoveto(mcs, vmc_ref_rel_link rel pose(bot_link));
         affix(mcs, bot_link);
```

continued on next page

Example 6.3 (continued)

```
            mk_vmc_mcs := mcs;
        end
    else
        mk_vmc_mcs := wlkup(mcs_name);
end;

            { ncv_install_<machine> constructs nc_machine class
             from selected robot in workcell }

function ncv_install_vmc(): boolean; { TRUE if all OK }
var   vmc_handle, vmc_ref: shape;
      bot_name, handle_name, ref_name: string;
begin
            { vmc_30_robot_model is the SILSPEC }
   bot_name := name(vmc_30_robot_model);
   if object_exists(bot_name) then
      begin
            { Construct move_handle and reference shapes }
            vmc_handle := mk_vmc_handle();
            handle_name := name(vmc_handle);
            vmc_ref := mk_vmc_mcs();
            ref_name := name(vmc_ref);
            gcode_stmt := vmc_gcode_set_defaults();
            { Construct nc_machine }
            vmc :=
                mk_nc_machine(wlkup(bot_name) as_type robot,
                handle_name, handle_name, handle_name,
                handle_name, handle_name, null_string,
                2, 1, 3, ncv_null_link, ncv_null_link, ncv_null_link,
                bot_name, 0, null_string, 0,
                ref_name, pose(vmc_ref), home_of(bot_name),
                handle_name, vmc_ncv$pendant, incv$monitor,
                mk_machine_status(default_gcodes,
                                  default_mcodes,
                'idle', 'absolute', 'linear', 'off', false, false,
                'metric', 'linear', 1.),
                vmc_gtable, vmc_mtable, vmc_gc_translator,
                emptylist(gc_rules));
      end;
end;
```

Chapter 7

Modeling NC Tooling

This chapter introduces the following topics:

- *The Tooling Assembly*
- *Cutting Tool*
- *Tool Holder*
- *Tool Changer*
- *Tool Library*
- *Setting Cutter Offsets*
  - Setting Offsets for End Effectors (Inverse Kinematics)
  - Setting Offsets in Joint Vectors
- *Assigning Additional Properties*
  - Collision Detection
  - Material Removal
  - Spindle On/Off

"Classes and Inheritance" on page 2-24 explained how to apply the concept of classes and inheritance to add properties to an existing object (specialization of a object) without having to examine the low-level properties of the object.

This chapter describes how to construct specialized objects in Soft Machines to model NC tooling; in particular, how to create special classes of SIL objects to contain properties related to cutters, tool holders and tool changers.

The Tooling Assembly

Figure 7-1 shows the class hierarchy of objects used in Soft Machines.

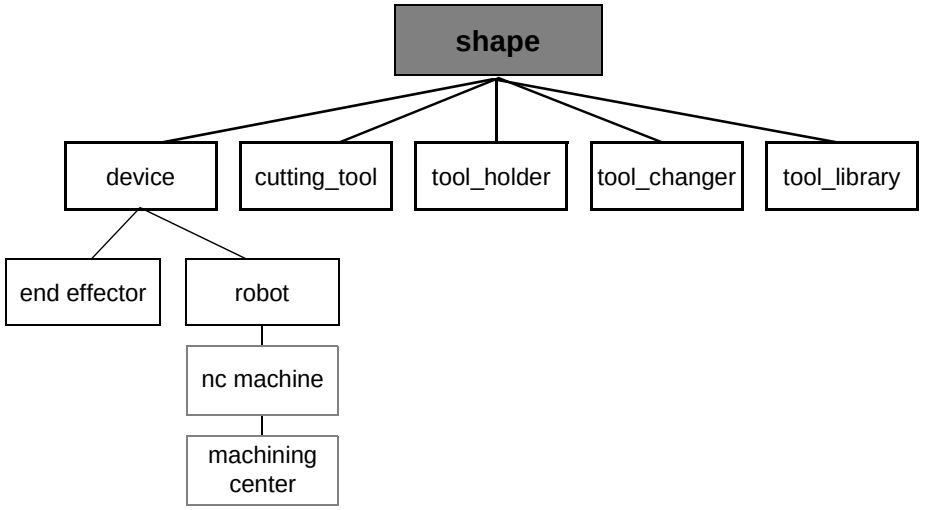


Figure 7-1 Simplified class hierarchy of NC-related objects

In the NC simulator, the tooling assembly can be classified into three components: the cutting tool, tool holder and tool changer.

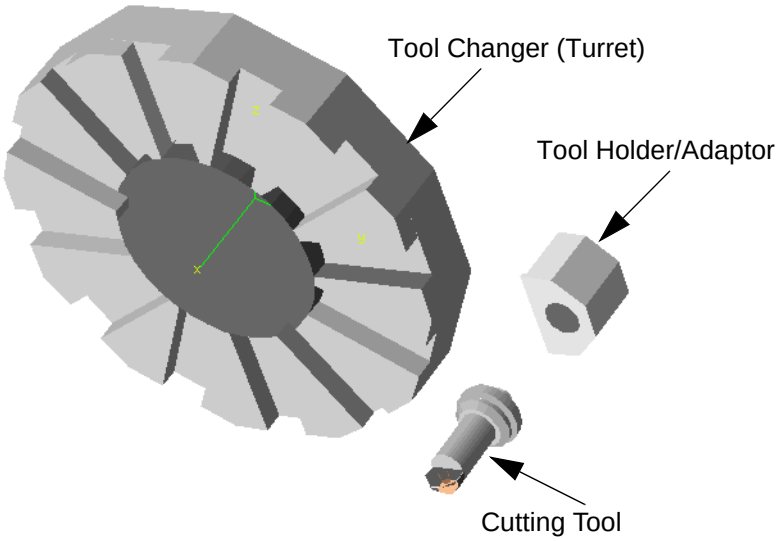


Figure 7-2 NC tooling: tools for turning

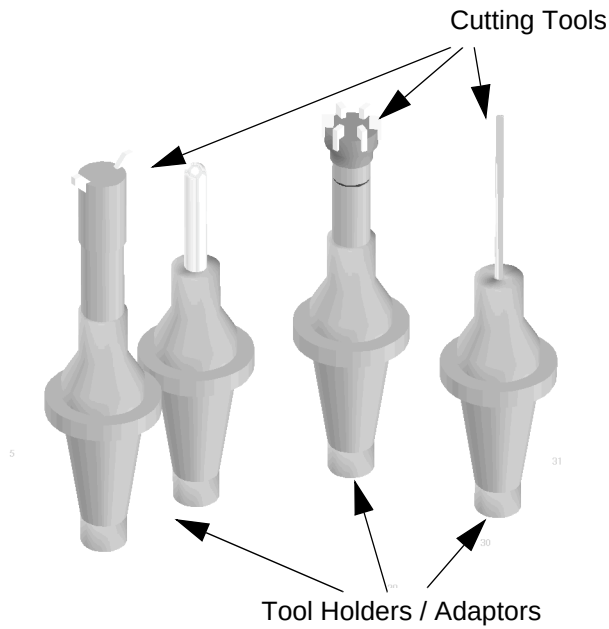


Figure 7-3 NC tooling: tools for a machining center

Cutting Tool

A cutting tool is the cutter that performs the actual machining operations, such as drills, end-mills, cutter inserts, etc.

Tool Holder

A tool holder is used as a tool holding device for cutting tools, such as drill chucks, collets, V-flange adapters, etc. In a machining center, tool holder/cutting tool assemblies are usually mounted on a tool magazine when not performing machining operations. An automatic tool changer will mount the tool holder to the machine spindle when a tool-change command is executed.

Tool Changer

A tool changer is a device for changing cutters between machining operations. In a turning machine, a tool changer usually contains a turret mounting multiple cutter assemblies (Figure 7-4). In a machining center, the tool changer usually combines a tool magazine, which stores the tool holder/cutter assemblies, and mechanisms (usually a mechanical arm) for exchanging cutter assemblies between the tool magazine and the machine spindle (Figure 7-5).

Tool Library

A **tool library** is a collection of tool holder/cutter assemblies mounted on a tool changer. Different NC part programs require different combinations of tool holders and cutters. Tool libraries provide a means of storing these different combinations.

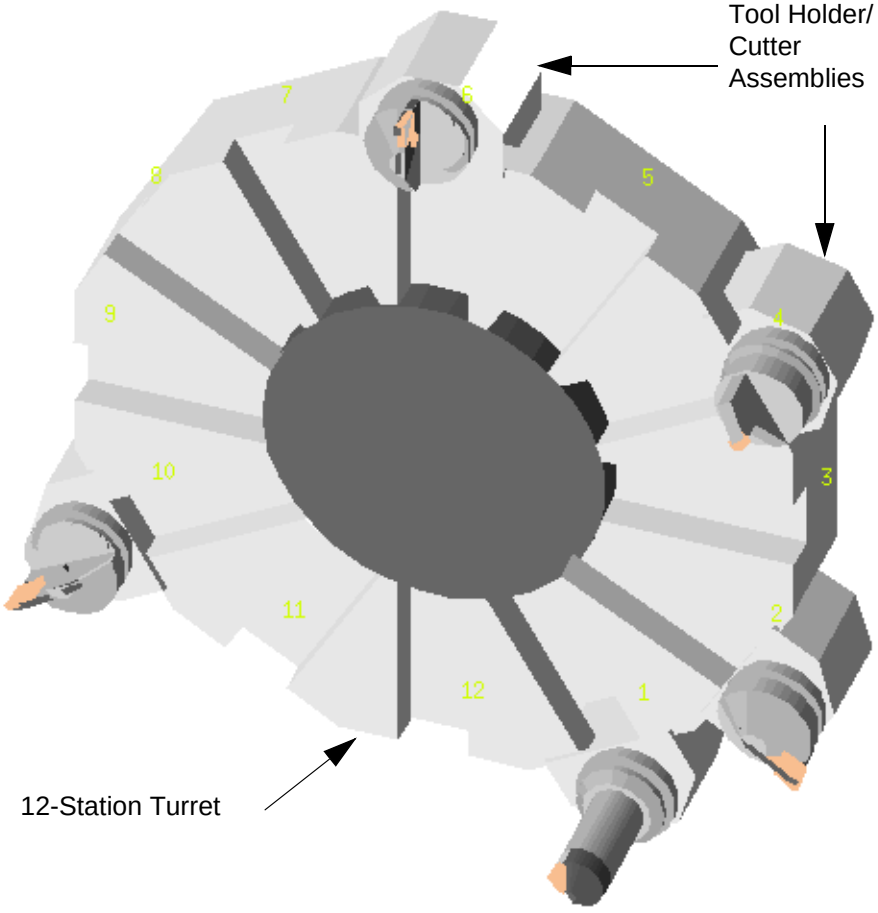


Figure 7-4 Tool library for CNC turret lathe

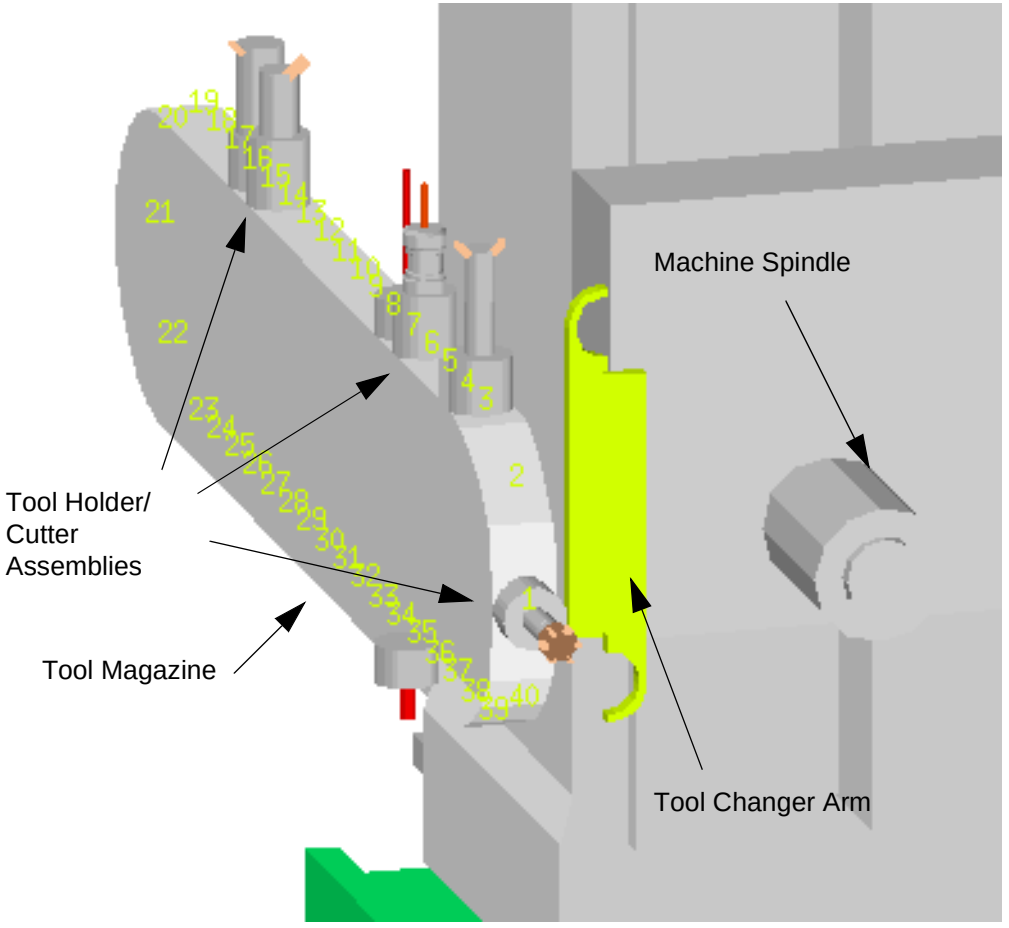


Figure 7-5 Tool changer for horizontal machining center

Cutting Tool

The class **cutting_tool** is created as a subclass of shape:

```
new_class(cutting_tool,
superclass: generalize: shape,
flange: frame,
tip: frame,
cutter_type: id,
diam: real,
length: real,
cutting_angle: rangle,
flute_length: real,
smurfiness: boolean);
```

FIELD	TYPE	DESCRIPTION
flange	**frame**	Flange of cutting tool **(in_frame pose(cutter))**. Defines where the cutting tool is to be mounted onto a tool holder.
tip	**frame**	Tip of cutting tool **(in_frame pose(cutter))**. Computes cutter offsets and cutter path tracing.
cutter_type	**id**	ID used to identify cutter types.
diam	**real**	Diameter of cutter (unit in centimeters).
length	**real**	Length of cutter (unit in centimeters).
cutting_angle	**rangle**	Cutter angle (radian).
flute_length	**real**	Flute length, or length of cutting edge (unit in centimeter).
smurfiness	**boolean**	Currently not used.

Table 7-1 **cutting_tool** field descriptions

Figure 7-6 and Figure 7-7 show two examples of cutting tool models—one typical for milling operations, one for turning operations.

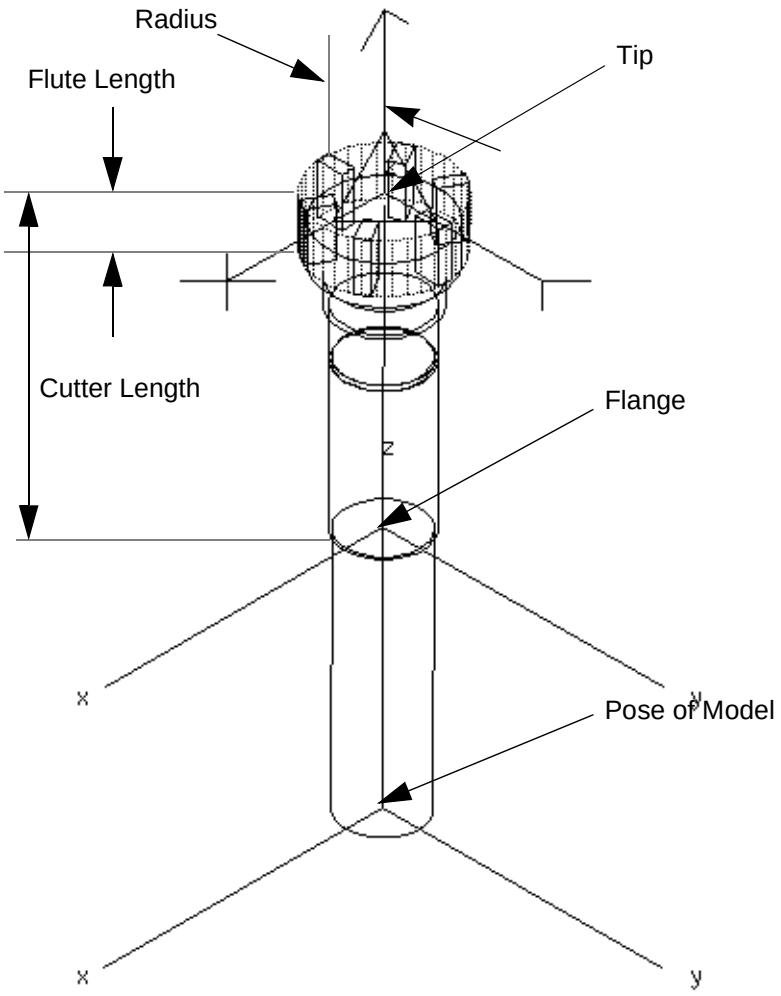


Figure 7-6 Cutting tool (end mill with inserts)

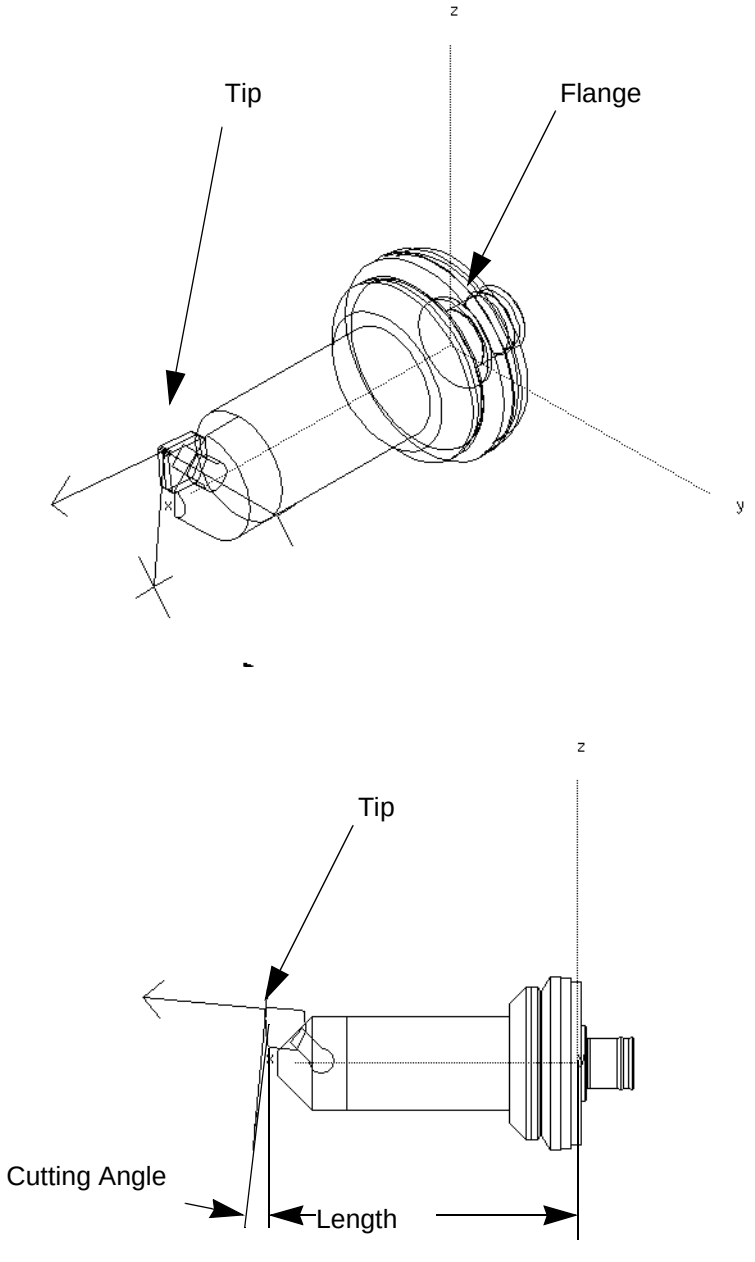


Figure 7-7 Cutting tool (boring bar with inserts)

The following steps show how to construct a **cutting_tool**:

1. Create a regular Soft Machines model using the **Modeling** menu or import from other CAD systems.

   NOTE Chapter 3, “Modeling”, of the Soft Machines User’s Manual provides more information.

2. Create empty shapes or frames and move them to the desired posed for flange and tip of cutter (refer to Figure 7-6 and Figure 7-7).
3. Use the Tool Setup panel to teach the flange and tip to the cutting tool model.

   NOTE The “Cutting Tools” section of Chapter 6, “Modeling NC Tooling”, in the Soft Machines User’s Manual provides more information.

4. Fill in additional properties if required.
5. Construct **cutting_tool** subclass.

Example 7.1 illustrates how this can be done in SIL.

Example 7.1

Suppose there are 3 models, **END_MILL**, **MILL_FLANGE** and **MILL_TIP**, representing the CAD model, flange and tip respectively of the cutting tool. We declare 3 shapes as follows:

```
cutter_shape == wlkup('END_MILL');
cutter_flange == wlkup('MILL_FLANGE');
cutter_tip == wlkup('MILL_TIP');
```

Flange and tip of the cutting tool can be defined as follows:

```
fr_cutter == pose(cutter_shape);
fr_flange == pose(cutter_flange) in_frame fr_cutter;
fr_tip == pose(cutter_tip) in_frame fr_cutter;
```

continued on next page

Example 7.1 (continued)

Construct cutting tool:

```
cutter ==
mk_cutting_tool(
        cutter_shape, fr_flange, fr_tip,
        generic_id, 0., 0., 0. as_type dangle, 0., smurf);
```

Other parameters can be added as follows:

```
cutter.length == fr_tip.zc - fr_flange.zc;
cutter.radius == 0.25 * inch; { For 0.5 inch end mill }
                … etc.
```

Tool Holder

The class **tool_holder** is declared as

```
new_class(tool_holder,
superclass: generalize: shape,
flange: frame,
mount: frame,
cutter: cutting_tool,
holder_type: id,
cutter_types: list_of(id));
```

FIELD	TYPE	DESCRIPTION
flange	**frame**	Flange of tool holder. Defines when tool holder is mounted onto the tool changer.
mount	**frame**	Cutter mount position.
cutter	**cutting_tool**	Cutting tool mounted to the tool holder.

Table 7-2 **tool_holder** field descriptions

FIELD	TYPE	DESCRIPTION
holder_type	**id**	Identifier for type of tool holder.
cutter_types	**list_of(id)**	Identifiers for cutters compatible with this holder (used in conjunction with **cutting_tool.cutter_type**).

Table 7-2 **tool_holder** field descriptions (continued)

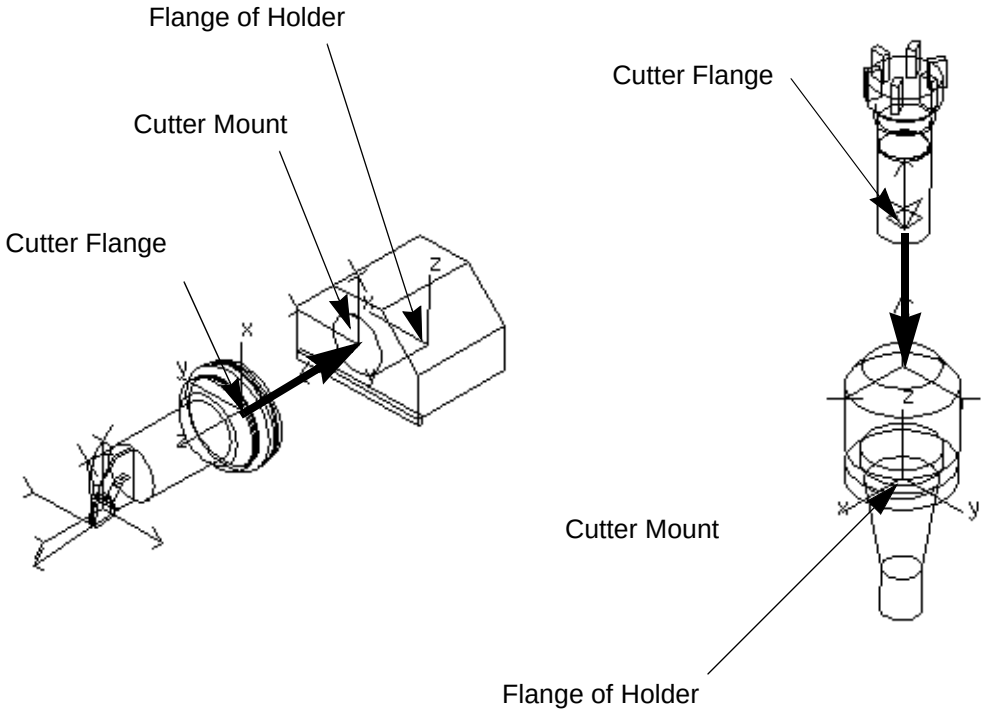


Figure 7-8 Mounting cutting tools on tool holders

Figure 7-8 illustrates the relationships among the different fields of **tool_holder**. When a **cutting_tool** is mounted onto a **tool_holder**, the cutter is moved so that the **flange** of the **cutting_tool** moves to the **mount** frame of the **tool_holder**.

Given a cutting tool **ct** and a tool holder **th**, we can mount **ct** onto **th** as follows:

Compute move vector:

```
ct_rel_th := pose(th) * th.mount * invert(ct.flange);
```

Move cutter to flange of holder, affix cutter to holder:

```
moveto(ct, ct_rel_th);
affix(ct, th);
```

Example 7.2 illustrates how to construct a tool holder in SIL:

Example 7.2

Suppose there are 3 models, **HOLDER**, **HOLDER_FLANGE** and **HOLDER_MOUNT**, representing the CAD model, flange and cutter mount frame respectively of a tool holder. We construct the tool holder as follows:

```
holder ==
mk_tool_holder(wlkup('HOLDER'),
(pose('HOLDER_FLANGE') in_frame pose('HOLDER'),
 pose('HOLDER_MOUNT') in_frame pose('HOLDER'),
 nil as_type cutting_tool,
 generic_id, list(generic_id));
```

The **cutter** field should be filled in after a **cutting_tool** has been mounted.

Tool Changer

The class **tool_changer** is declared as

```
new_class(tool_changer,
superclass: generalize: shape,
mounts: array_of(mount_point),
flange: frame,
max_mounts: integer);
```

for which

```
type mount_point = lrecord
pos: frame;
indx: integer;
holder_type: id;
holder: tool_holder;
end;;
```

FIELD	TYPE	DESCRIPTION
max_mounts	**integer**	Maximum number of stations in tool changer.
pos	**frame**	Position of holder mount.
indx	**integer**	Station number.
holder_type	**id**	Identifier for type of tool holder, used in conjunction with: **tool_holder.holder_type**.
holder	**tool_holder**	Tool holder mounted at station.

Table 7-3 **tool_changer** field descriptions

Figures 7-9 and 7-10 show two examples of tool changers: a turret, common on turning machines, and a chain type tool changer, common on machining centers. Each tool changer contains a series of stations (defined by the field **mounts**) for mounting tool holder/cutter assembly.

When we mount a tool holder **th** to a tool changer **tc**, we move the **th** so that the **flange** of the holder is at the position specified by **tc.mounts[n].pos** (where **n** is an integer):

```
th_rel_tc == pose(tc) * tc.mounts[n].pos * invert(th.flange);
moveto(th, th_rel_tc);
affix(th, tc);
```

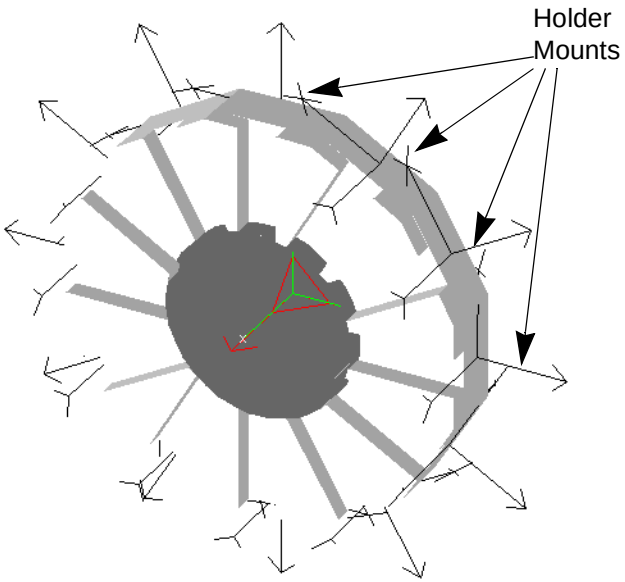


Figure 7-9 Turret type tool changer

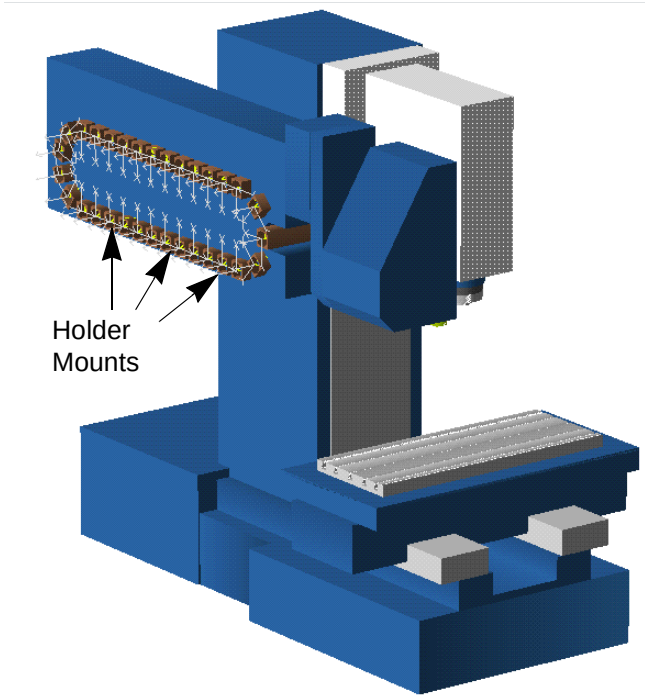


Figure 7-10 Chain type tool changer

Example 7.3 shows how to construct a tool changer.

Example 7.3

Suppose we want to construct a tool changer from the object **TURRET**, which has the following subparts (children):

TURRET/FRAMES/{F0, F1, F2, … , FN}

To compute the number of stations, we check the number of subparts under **TURRET/FRAMES**:

```
max_mnt ==
        length(all_descendants(wlkup('TURRET/FRAMES')));
mnts == array_create(mount_point, max_mnt - 1);
```

continued on next page

Example 7.3 (continued)

Attach properties to each mount point:

```
var i, stn_no: integer;
   fr: frame;;
turret_pose == pose('TURRET');
for i := 0 to max_mnt-1 do
begin
   fr :=    pose(concat('TURRET/FRAMES/F',int2str(i)))
                        in_frame turret_pose;
   stn_no := i+1;
   mnts[i] := mk_mount_point(fr, stn_no, generic_id,
                                    nil as_type tool_holder);
end;
```

Create tool changer:

```
tc == mk_tool_changer(wlkup('TURRET'), mnts, max_mnt);
```

Tool Library

Class definition of a tool library (**tool_lib**) is

```
new_class(tool_lib,
  superclass: generalize: shape,
  changer: tool_changer,
  aux: universal);
```

where **changer** is the tool changer; and **aux** is a **universal** field designed to incorporate data from external tool databases.

A tool library is constructed by mounting tool holders and cutting tools at user-defined stations and then saved for later use. Tool libraries can be assembled in different combinations using the same tool holders and cutters. For example, in Figure 7-4 on page 7-5, the same tool holder (an ID adaptor) is used to hold different cutting tools at different stations.

To mount a tool library to an NC machine, we move the **tool_lib** to the pose of the object defined by the **changer_mount** field in **nc_machine**. We define the procedure **mount_tlib** as follows:

```
procedure mount_tlib(tl:tool_lib; m:nc_machine);
var s: string;
begin
   s := name(tl);
   if (m.tlib = null_string) then
   begin
      m.tlib := s;
      imoveto(s, pose(m.changer_mount));
      affix(s, m.changer_mount);
   end
   else writeln('mount_tlib: changer mount on machine is
                 occupied');
end;
```

Figure 6-1 on page 6-3 illustrates that a machine assembly consists of a tooling assembly (a **tool_lib**) attached to a machine tool model (**nc_machine**). The procedure **mount_tlib** completes the step of constructing such a machine assembly.

It is often desirable to inquire about which tool holder and cutting tool is being used at a certain point in time. For example, to trace the cutter path, we need to find out the position of the tip of the active cutting tool. All the tooling-related information about an NC machine can be retrieved from the object **nc_machine**.

To retrieve the active tool holder, we define the function **get_active_holder**:

```
function get_active_holder(m: nc_machine): tool_holder;
var   tl: tool_lib;
      tc: tool_changer;
      mnt: mount_point;
      th: tool_holder;
begin
   tl := specialize_to(wlkup(m.tlib), tool_lib);
   th := nil as_type tool_holder;
   if not(nul(tl)) then
   begin
   tc := tl.changer;
   if not(nul(tc)) then
   begin
      { get_active_station returns the active mount_point }
   mnt := get_active_station(tc, m.station_no);
   th := mnt.holder;
   end;
   end;
   get_active_holder := th;
end;
```

Note the usage of the function **specialize_to** to retrieve the subclass **tool_lib** from a **shape**, and the function **nul** to check whether an object exists or not (**nul** returns **TRUE** if an object is a null object).

To retrieve the active cutting tool, we define **get_active_cutter**:

```
function get_active_cutter(m: nc_machine): cutting_tool;
var   ct: cutting_tool;
      th: tool_holder;
begin
   ct := nil as_type cutting_tool;
   th := get_active_holder(m);
   if not(nul(th)) then ct := th.cutter;
   get_active_cutter := ct;
end;
```

To find the tip of the active cutting tool:

```
function get_cutter_tip(m: nc_machine): frame;
var       ct: cutting_tool;
begin
   ct := get_active_cutter(m);
   if not(nul(ct))    then get_cutter_tip:= pose(ct) * ct.tip
                      else get_cutter_tip := null_frame;
end;
```

A more general example is shown in Example 7.4.

Example 7.4

get_holder_on_flange checks if **tool_holder** is affixed to flange of machine, such as in the case of machining center and milling machine:

```
function get_holder_on_flange(m: nc_machine): tool_holder;
var   th: tool_holder;
      sh: shape;
begin
   th := nil as_type tool_holder;
   for sh in affixed_shapes(name(m)*'_FLANGE') do
   begin
      if is_tool_holder(sh) then
      th := specialize_to(sh, tool_holder);
   end;
   get_holder_on_flange := th;
end;
```

get_cutter_tip returns pose of cutter tip in World coordinates:

```
function get_cutter_tip(ct: cutting_tool): frame;
begin
    get_cutter_tip := pose(ct)*tip(ct);
end;
```

continued on next page

Example 7.4 (continued)

Two possible cases for **get_active_cutter** are

- Turret: tool library is mounted to the flange of the machine: get cutter at **current_station**
- Chain-type tool changer: holder is mounted to the flange of the machine: get cutter at flange.

```
function get_active_cutter(m: nc_machine): cutting_tool;
var ct: cutting_tool;
   th: tool_holder;
   tl: tool_lib;
begin
   ct := nil as_type cutting_tool;
   tl := specialize_to(wlkup(m.tlib), tool_lib);
   if not(nul(tl)) then
   begin
```

{ Tool holder is mounted on flange? If not, grab holder from tool library }

```
      th := get_holder_on_flange(m);
      if (nul(th)) then th := get_active_holder(m);
      if not(nul(th)) then ct := th.cutter;
   end;
   get_active_cutter := ct;
end;
```

Cutter tip can be either tip of cutting tool or tip of end effector (for robots):

```
function get_cutter_tip(m: nc_machine): frame;
var ct: cutting_tool;
   sh: shape;
   f: frame;
begin
   ct := get_active_cutter(m);
   if not(nul(ct)) then f := get_cutter_tip(ct)
   else
      begin
         sh := end_effector_of(generalize(m));
         if not(nul(sh)) then f := pose(sh)
         else f := flange(m);
      end;
   get_cutter_tip := f;
end;
```

Interface to an External Tool Database

Soft Machines allows data from an external database to be integrated into the tool library object through the universal field **aux** in the **tool_lib** object class.

The **aux** field gives us the flexibility of incorporating data of many different types by casting them into type **universal**, and hence the ability to upload tool data from different databases, each with its own special data format.

Example 7.5 shows examples of attaching different data types to a tool library.

Example 7.5

Data structure for Kearney and Tracker Moduline Series:

```
type kt_tool_data = lrecord
   stn_no: integer;
   tool_id: integer;
   description: string;
   dia: real;
   loc: real;
   corner_radius: real;
   preset: real;
end;;

kt_moduline_tool_data := array(
   mk_kt_tool_data(1, 1718120, 'END MILL', 2., 4., 0.120, 8.25),
   mk_kt_tool_data(2, 1724001, 'END MILL', 2., 6., 0., 12.125),
   mk_kt_tool_data(3, 0643931, 'BALL MILL', 0.75, 2.25, 0.375, 6.25),
   mk_kt_tool_data(4, 0614931, 'BALL MILL', 0.5, 2., 0.25, 4.92),
   mk_kt_tool_data(5, 1111110, 'SPECIAL', 2., 0., 0., 9.),
   mk_kt_tool_data(6, 1551004, 'END MILL', 0.25, 0.63, 0., 9.06),
   mk_kt_tool_data(7, 0155001, 'FACE MILL', 6., 0.71, 0., 5.49),
   mk_kt_tool_data(8, 1680001, 'END-MILL', 1.5, 2.00, 0., 6.25),
   mk_kt_tool_data(9, 1633001, 'END-MILL', 0.75, 2.25, 0.375,
                           6.25+0.375),
   mk_kt_tool_data(10, 2525911, 'DRILL', .25, 2.750, 0., 5.870),
   mk_kt_tool_data(11, 0025004, 'END-MILL', .188, .500, 0., 8.930),
```

continued on next page

Example 7.5 (continued)

```
   mk_kt_tool_data(12, 0, 'EMPTY POCKET', 0., 0., 0., 0.),
   mk_kt_tool_data(13, 0, 'EMPTY POCKET', 0., 0., 0., 0.),
   mk_kt_tool_data(14, 0, 'EMPTY POCKET', 0., 0., 0., 0.),
   mk_kt_tool_data(15, 0, 'EMPTY POCKET', 0., 0., 0., 0.),
   mk_kt_tool_data(16, 0, 'EMPTY POCKET', 0., 0., 0., 0.),
   mk_kt_tool_data(17, 0, 'EMPTY POCKET', 0., 0., 0., 0.),
   mk_kt_tool_data(18, 0, 'EMPTY POCKET', 0., 0., 0., 0.),
   mk_kt_tool_data(19, 0, 'EMPTY POCKET', 0., 0., 0., 0.),
   mk_kt_tool_data(20, 0, 'EMPTY POCKET', 0., 0., 0., 0.));
```

active_tlib is a global variable of type **tool_lib**:

```
   active_tlib.aux := kt_moduline_tool_data as_type universal;
```

Data structure for VMC (Vertical Machining Center):

```
   type vmc_tdata = lrecord
      stn_no: integer;
      tool_id: integer;
      description: string;
      dia: real;
      tool_offsets: point;
   end;;

mc_tool_data := array(
   mk_vmc_tdata(1, 1, '#1 CENTER DRILL', 0.125,
                      mk_point(0.,0.,8.)),
   mk_vmc_tdata(2, 2, '0.0635 DRILL', 0.0635, mk_point(0.,0.,8.)),
   mk_vmc_tdata(3, 3, '0.0890 DRILL', 0.0890, mk_point(0.,0.,8.)),
   mk_vmc_tdata(4, 4, '0.120 DRILL', 0.120, mk_point(0.,0.,8.)),
   mk_vmc_tdata(5, 5, '0.128 DRILL', 0.128, mk_point(0.,0.,8.)),
   mk_vmc_tdata(6, 6, '0.147 DRILL', 0.147, mk_point(0.,0.,8.)),
   mk_vmc_tdata(7, 7, '0.166 DRILL', 0.166, mk_point(0.,0.,8.)),
   mk_vmc_tdata(8, 8, '0.201 DRILL', 0.201, mk_point(0.,0.,8.)),
   mk_vmc_tdata(9, 9, '0.391 DRILL', 0.391, mk_point(0.,0.,8.)),
   mk_vmc_tdata(10, 10, '0.641 DRILL', 0.641, mk_point(0.,0.,8.)),
   mk_vmc_tdata(11, 11, '0.375 END MILL', 0.375,
                      mk_point(0.,0.,7.313)),
   vmk_vmc_tdata(12, 12, '0.1875 END MILL', 0.1875,
                      mk_point(0.,0.,8.)),
```

continued on next page

Example 7.5 (continued)

```
mk_vmc_tdata(13, 13, 'COUNTER SINK', 0.5, mk_point(0.,0.,8.)),
mk_vmc_tdata(14, 14, '0.125 END MILL', 0.125,
                    mk_point(0.,0.,8.)),
mk_vmc_tdata(15, 15, '0.250 END MILL', 0.250,
                    mk_point(0.,0.,8.)),
mk_vmc_tdata(16, 16, '0.625 DRILL', 0.625, mk_point(0.,0.,8.)),
mk_vmc_tdata(17, 17, 'EMPTY', 0., null_point),
mk_vmc_tdata(18, 18, 'EMPTY', 0., null_point),
mk_vmc_tdata(19, 19, 'EMPTY', 0., null_point),
mk_vmc_tdata(20, 20, 'EMPTY', 0., null_point),
mk_vmc_tdata(21, 21, 'EMPTY', 0., null_point),
mk_vmc_tdata(22, 22, 'EMPTY', 0., null_point),
mk_vmc_tdata(23, 23, 'EMPTY', 0., null_point),
mk_vmc_tdata(24, 24, 'EMPTY', 0., null_point),
mk_vmc_tdata(25, 25, 'EMPTY', 0., null_point),
mk_vmc_tdata(26, 26, 'EMPTY', 0., null_point),
mk_vmc_tdata(27, 27, 'EMPTY', 0., null_point),
mk_vmc_tdata(28, 28, 'EMPTY', 0., null_point),
mk_vmc_tdata(29, 29, 'EMPTY', 0., null_point),
mk_vmc_tdata(30, 30, 'EMPTY', 0., null_point));
```

active_tlib is a global variable of type **tool_lib**:

```
active_tlib.aux := vmc_tool_data as_type universal;
```

To retrieve the auxiliary data from a tool library, the **aux** field can be cast from type **universal** to the data type we want. In Example 7.5, the **aux** field in the global variable **active_tlib** contains two possible data types. The first step is to validate the data type using the **type_of** operator, then cast the **aux** field accordingly:

```
if (type_of(active_tlib.aux) = type_of(kt_moduline_tool_data)) then
      my_tool_data == active_tlib.aux as_type darray of kt_tdata;

if (type_of(active_tlib.aux) = type_of(vmc_tool_data)) then
      my_tool_data == active_tlib.aux as_type darray of vmc_tdata;
```

Since **universal** is a supertype, any SIL objects can be legally cast to a **universal**. Besides ordinary data, functions and procedures can also be attached by using SIL closures, allowing us to incorporate special

routines for manipulating tool data (see Example 7.6). In fact, tool models can be generated automatically by adding modeling functions to any tool library!

Example 7.6

Suppose the SIL procedure **import_tool_data(<string>)** imports and constructs tooling models from an external database. We attach it to a tool library by creating a closure:

```
tool_import_cl ==
   mk_closure("import_tool_data, function(ob, string));
active_tlib := mk_tool_lib(mk_empty_shape(), nil as_type
tool_changer, tool_import_cl as_type universal);
```

To retrieve the procedure from the tool library:

```
tlib_fn == active_tlib.aux as_type closure(ob, string);
```

To execute the procedure:

```
tlib_fn(CAD_file_name);
```

NOTE The original tool library contains empty shapes. All tooling models are being generated by the procedure **import_tool_data**.

Setting Cutter Offsets

Chapter 6, "Modeling NC Machines", explained how to set NC coordinate systems by constructing empty shapes (move handles, reference shapes) and affixing them to different subparts of the machines or by defining a set of joint vectors as references for forward kinematics moves.

In addition to machine and work coordinates, an NC simulator must deal with the properties of the tooling used. Most importantly, tool lengths and other cutter offsets must be handled correctly to generate an accurate cutter path. We have already discussed how to add tool parameters to a tool library. This section shows how these parameters can be used to affect an NC simulation.

Setting Offsets for End Effectors (Inverse Kinematics)

The simplest method for setting cutter offsets is to position the move handle at an offset specified by the tool parameters. Usually, the offset is set to be the vector between the flange of the machine and the tip of the cutter (see Figure 7-11 and Figure 7-12).

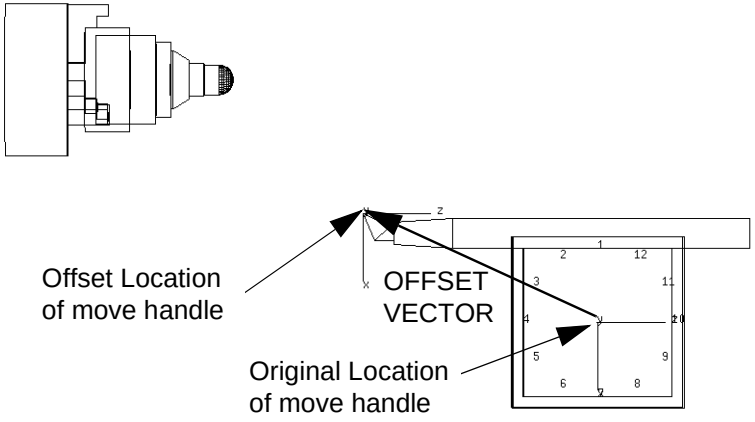


Figure 7-11 Setting cutter offset (turning machine)

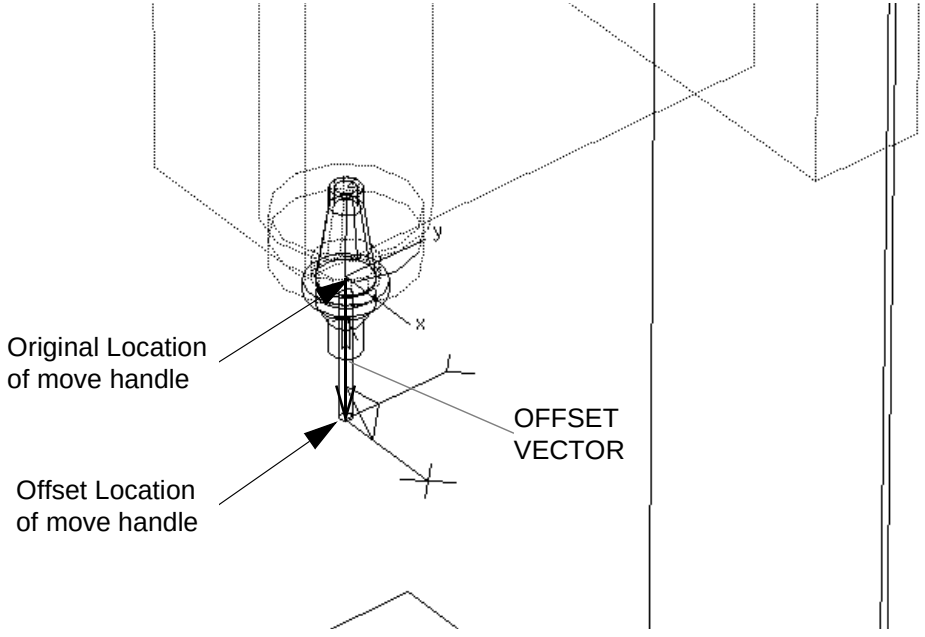


Figure 7-12 Setting cutter offset (milling machine)

To determine the tool offset vector, you can either compute it from the cutting tool model, or use information provided from an external tool database. Example 7.7 shows how to calculate the pose of the tip of the active cutter on an NC machine.

Example 7.7

Cutter offset can be activated by repositioning the move handle to the tip of the active cutter:

```
procedure ncv_set_cutter_offset(m: nc_machine);
var p: point;
    bot_flange, handle: shape;
begin
    handle := wlkup(name(m)*'_HANDLE');
    bot_flange := wlkup(name(m)*'_FLANGE');
        { Unaffix move handle from flange of machine }
    if (affixed(handle, bot_flange)) then unaffix(handle, bot_flange);
        { Move handle to new point—use point instead of frame to retain
        orientation of move handle }
    p := pos(get_cutter_tip(m));
    imoveto(handle, p);

    affix(handle, bot_flange);
end;
```

The same concept can be used if the offset vector is determined by an external database. We summarize the steps as follows:

1. Reset all previous tool offsets by moving the move handle to the flange of the machine (remembering to unaffix the handle from the flange before the move).
2. Move the handle to a new point as defined by the offset vector.
3. Affix handle to flange.

Setting Offsets in Joint Vectors

Simulations consisting of forward kinematics (JV) moves require cutter offsets to be represented in joint vectors. “NC Coordinates in Joint Space” on page 6-14, showed how to execute a 6-axis move with the expression

```
moveto(mc, ncv_axes_to_jv(mc, x, y, z, a, b, c) + mc.ref_jv[i]);
```

where **mc** is a **machining_center**, a subclass of **nc_machine**;

and, **mc.ref_jv[i]** is machine reference coordinates defined in JV.

A tool offset vector can be converted into a joint vector in the same manner as an NC move statement is converted into a joint vector. The expression becomes

```
offset_jv == mc.ref_jv[i] + tool_offsets;
moveto(mc, ncv_axes_to_jv(mc, x, y, z, a, b, c) +offset_jv);
```

Example 7.8

Suppose the SIL procedure **get_tlo(<nc_machine>, <gcode_info>)** returns the tool length offset from tool database; we define a function **set_tlo** as follows:

```
function set_tlo(m: nc_machine; g: gcode_info): jv;
var axes:     darray of real;
              j: integer;
begin
   axes := array_create(real,6);
   for j := 0 to 6 do axes[j] := 0.;
   { Offset Z axis }
   axes[abs(m.z_link)] := get_tlo(m, g)*sgn(m.z_link);
   set_tlo := mk_jv(axes[1],axes[2],axes[3],
                    axes[4],axes[5],axes[6]);
end;
```

Assigning Additional Properties

In addition to geometric properties associated with NC tooling, additional properties can be assigned either by built-in simulation rules or by manipulation of the tooling objects themselves. If necessary, we can construct specializations (subclasses) of NC tooling to represent different types of cutting tools. For example, some machining processes employ programmable probes for in-process measurement functions. These probe heads can be considered as specializations of cutting tools—additional parameters relating to probe measurements can be added, and probing functions can be attached by using SIL closures.

Collision Detection

An example of using “rules” based properties is collision detection in Soft Machines. Here, a tool is assumed to be actually cutting when

- Machine spindle is “on”
- Machine is not in “rapid” (positioning) mode
- Cutter is at the cutting position (i.e., active cutter is not a null model)
- Machine coolant is “on” (which is true in most cases)

If any of these conditions is *not* satisfied, you need to activate collision detection between the cutter and the part. Conversely, you need to exclude the cutting tool from collision detection when it is performing cutting operations. Example 7.9 shows how to exclude collision detection for the active cutter.

Example 7.9

Supposing the SIL global variable **ncv_turned_part** represents the part stock, and a collision checklist is set up which includes part stock and tool library, We need to exclude the active cutter from the collision checklist:

```
procedure set_cutter_coldet(m: nc_machine);
var ct:    cutting_tool;
begin
   ct := get_active_cutter(m);
   if (not(nul(ncv_turned_part)) and not(nul(ct))) then
   begin
      if ((lowercase(nc.status.spindle) = 'on')
      and (lowercase(nc.status.interpolation <> 'rapid')
      and (lowercase(nc.status.coolant) = true)) then
          add_exclude(ct, ncv_turned_part);
   end;
end;
```

Material Removal

Example 7.10 shows a “time-sliced” based approach in computing material removal simulation. The “swept volume” of a cutter tool is computed as it moves along in space during a time interval. The swept volume is subtracted from the part stock model to create a new shape representing the part in process. We establish the following rules before material removal is applied:

- Machine is “on”.
- Machine is not in “rapid” mode.
- Cutter is at the cutting position.
- No tool change during the time elapsed.

Example 7.10

```
task do_material_removal(m: nc_machine);
var ct, ct_prev: cutting_tool;
   cs: string;
   fr_prev: frame;
begin
   cs := m.status.current_state;
   ct_prev := get_active_cutter(m);
   fr_prev := pose(ct_prev);
   ok := true;
   if (while cs = 'running') then
   begin
      delay(mtlrem_update_interval); { Sleep ... }
      cs := m.status.current_state;
      ct := get_active_cutter(m);
      if not(nul(ct)) then { Cutter in position? }
      begin { Tool Change? }
         if (name(ct) = name(ct_prev)) and
                  (pose(ct) <> fr_prev)) then
         ok := do_metal_removal(ncv_turned_part,
                              ct,fr_prev);
         if ok then
            begin
               fr_prev := pose(ct); ct_prev := ct;
            end
         else
            writeln('Volume subtraction failed');
      end;
      last_dpy_clock_time := clock;
      ex_actions(clock+mtlrem_update_interval);
   end;
end;
```

Spindle On/Off

We simulate the motion of the spindle, or more specially, the rotation of the cutting tool mounted to the spindle, by manipulating its subobjects (children). The simplest method is to create a model representing the cutter revolution, adopt it under the cutting tool, and then hide it when the spindle is off, and show it when the spindle is turned on (Figure 7-13 and Example 7.10).

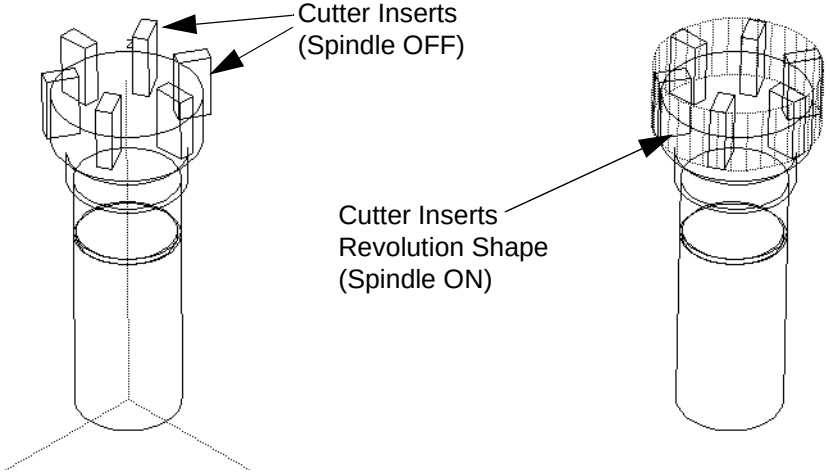


Figure 7-13 Simulating spindle ON/OFF

Example 7.11

Simulate spindle ON/OFF by hiding/unhiding **REVOLUTION** shape adopted by the cutting tool.

```
procedure spindle_on(cutter: shape);
var sh: shape;
begin
   for sh in all_descendants(cutter) do
   if (name(sh) = 'REVOLUTION') then unhide(sh);
end;

procedure spindle_off(cutter: shape);
var sh: shape;
begin
   for sh in all_descendants(cutter) do
   if (name(sh) = 'REVOLUTION') then hide(sh);
end;
```

Chapter 8

NC Tasks

This chapter discusses the following topics:

- ➢ *Creating SIL Tasks for NC Machines*
  - ■ Machine Independent Tasks
  - ■ Machine Dependent Tasks
- ➢ *Constructing and Customizing G and M Tables*
- ➢ *Error Logging and Reporting*
  - ■ Error Log
  - ■ Recording Movies

In order to simulate machine motions described by NC part programs, Soft Machines converts part program (G code) statements into equivalent SIL expressions. These SIL functions, procedures and tasks in turn manipulate workcell objects (such as machine and tooling models) to execute the corresponding simulation sequences. At the same time, part program errors are being monitored by error detection algorithms, which report errors either interactively or by storing them in an error log file. Graphics simulation can also be recorded in a “movie” for later replay.

This chapter gives an overview of how to develop SIL functions, procedures and tasks to control the NC simulator and attach it to the G and M codes of a machine controller. Soft Machines includes a library of SIL routines to help with the development of NC simulators. The most common machine functions are already built in. To incorporate them into the NC simulator, we can simply attach these standard routines to the G and M tables of the **nc_machine** object. Machine-specific tasks can be constructed with components from the library.

Creating SIL Tasks for NC Machines

The strategy for developing SIL tasks for NC machines can be summarized as follows:

1. Identify standard (machine independent) tasks applicable to the NC machine.
2. Construct custom SIL tasks for machine specific functions.
3. Create arrays for G and M tables and attach all relevant SIL tasks.

Machine Independent Tasks

A large majority of NC-related functions can be considered as machine independent, meaning their behavior is independent of the kinematics of the machine. These include generic G codes such as those for setting machine units (mm versus inch), setting feedrate, setting programming mode (absolute versus incremental), etc. Many G codes have equivalent functions in SIL. For example, **G70** (set units to inch) is equivalent to the SIL expression **do_set_units(4);** and **G71** (units in mm) is equivalent to **do_set_units(2);** (Example 8.1). Other G codes can be considered as preparatory functions and are used for presetting machine variables. These include codes such as **G53** (use machine coordinates), **G54** to **G59** (select work coordinates 1 to 6), **G93** to **G97** (feedrate declarations), etc.

Example 8.1

G70 and **G71** set units to inch and mm respectively.

Inputs: **nc** type **nc_machine** (current machine for simulation)

g type **gcode_info** (contains G code statement)

Returns: **gcode_status**

Contains error code (TRUE / FALSE), error messages, if any, and statement number.

continued on next page

Example 8.1 (continued)

```
task g70(nc: nc_machine; g: gcode_info): gcode_status;
begin
   do_set_units(4); { See intf_units_names_list }
   nc.status.unit := 'inch';
   g70 := mk_gcode_status(true, g.stmt_no,
      'do_set_units(4); { Inch programming }');
end;

task g71(nc: nc_machine; g: gcode_info): gcode_status;
begin
   do_set_units(2); { See intf_units_names_list }
   nc.status.unit := 'mm';
   g71 := mk_gcode_status(true, g.stmt_no,
      'do_set_units(2); { Metric programming }');
end;
```

Add codes to globals **default_gtable**:

```
add_gcode(70, 6, "g70, default_gtable);
add_gcode(71, 6, "g71, default_gtable);
```

Soft Machines includes two global arrays: **default_gtable** and **default_mtable** containing generic NC tasks described in the following pages.

Code	Description	Remarks
G0	Rapid Transverse	Set interpolation mode, then move machine (2 and 3 axes machines only)
G1	Linear Interpolation	See **G1**
G2	Circular Interpolation CW	See **G1**
G3	Circular Interpolation CCW	See **G1**
G4	Program Delay	Pause machine for specified time

Table 8-1 Default G code table

Code	Description	Remarks
G8	Disable Acceleration / Deceleration Control	Set machine status - acceleration and deceleration
G9	Enable Acceleration / Deceleration Control	See **G8**
G17	Plane Selection XY	Set machine status - declare plane used for circular interpolation
G18	Plane Selection ZX	See **G17**
G19	Plane Selection YZ	See **G17**
G28	Move axes to HOME position	Generic machine command - move machine to HOME position
G40	Radius Compensation OFF	Set status for cutter compensation
G41	Cutter Compensation LEFT	See **G41**
G42	Cutter Compensation RIGHT	See **G41**
G53	Move with respect to Machine Coordinates	Move axes in machine coordinates
G54	Move wrt Work Coordinates 1	Move axes in work coordinates (2 and 3 axes machines only)
G55	Move wrt Work Coordinates 2	See **G54**
G56	Move wrt Work Coordinates 3	See **G54**
G57	Move wrt Work Coordinates 4	See **G54**
G58	Move wrt Work Coordinates 5	See **G54**
G59	Move wrt Work Coordinates 6	See **G54**

Table 8-1 Default G code table (continued)

Code	Description	Remarks
G60	Single Direction Positioning	Set machine status for acceleration/deceleration
G61	Exact Stop Mode	See **G60**
G62	Corner Radius Override	See **G60**
G63	Tapping Mode	See **G60**
G64	Cutting Mode	See **G60**
G68	Coordinate System Rotation	Set machine status - coordinate system rotation
G69	Coordinate System Rotation	See **G69**
G70	Inch Programming	Set system unit (current_unit = inch)
G71	Metric (mm) Programming	Set system unit (current_unit = mm)
G73	Canned Cycle - Rapid Drilling	Declare active canned cycle, execute canned cycle
G74	Canned Cycle - Left Hand Tapping	See **G73**
G76	Canned Cycle - Fine Boring	See **G73**
G80	Canned Cycle Cancel	See **G73**
G81	Canned Cycle - Spot Drilling	See **G73**
G82	Canned Cycle - Counter Boring	See **G73**
G83	Canned Cycle - Peck Drilling	See **G73**
G84	Canned Cycle - Tapping	See **G73**
G85	Canned Cycle - Boring	See **G73**

Table 8-1 Default G code table (continued)

Code	Description	Remarks
G86	Canned Cycle - Rapid Boring	See **G73**
G90	Absolute Dimension Input	Set G code input status
G91	Incremental Dimension Input	See **G90**
G92	Preload Machine Registers	Set machine status
G93	Inverse Time Feedrate	Set machine status - feedrate control
G94	Inch or mm / min Feedrate	See **G93**
G95	Inch or mm / rev Feedrate	See **G93**
G96	Constant Surface Feedrate	See **G93**
G97	Revolution / min (rpm)	See **G93**
G98	Initial Level Return TRUE	Set canned cycle status, execute current canned cycle (see **G73 - G86**)
G99	Initial Level Return FALSE	See **G98**

Table 8-1 Default G code table (continued)

Code	Description	Remarks
M0	Stop Program	Set machine status
M1	Optional Stop	Set machine status
M2	End of Program	Stop simulation. Disable canned cycles
M3	Spindle OFF	Generic spindle command - For machining centers and milling machines only.

Table 8-2 Default M code table

Code	Description	Remarks
M4	Spindle ON - Clockwise	See **M3**
M5	Spindle ON - Counterclockwise	See **M4**
M8	Coolant ON	Set machine status - coolant
M9	Coolant OFF	See **M9**
M10	Clamp	Set machine status - clamps
M11	Unclamp	See **M10**

Table 8-2 Default M code table (continued)

IMPORTANT

Many G and M codes simply change the machine status variables (declared in **nc_machine.status**). It is the developer's responsibility to ensure the simulated machine behaves according to these variables.

To build a quick prototype, we can copy the two default tables and attach them to a new NC machine model. We use the commands **copy_gtable** and **copy_mtable**:

```
ok := copy_gtable(default_gtable, <target_gtable>);
ok := copy_mtable(default_mtable, <target_mtable>);
```

where **<target_gtable>** is an array of **g_function** (for G codes) and **<target_mtable>** is an array of **gcode_closure** (for M codes), and **ok** is a **boolean.**

The default tables can then be used as the foundation for further development and customization. Machine-dependent G is illustrated in Example 8.2.

Example 8.2

Suppose we want to attach the default tables **default_gtable** and **default_mtable** to the **nc_machine vmc**.

Create two arrays: **vmc_gtable** and **vmc_mtable**:

```
vmc_gtable == array_create(g_function, 400);
vmc_mtable == array_create(gcode_closure, 400);

ok1 == copy_gtable(default_gtable, vmc_gtable);
ok2 == copy_mtable(default_mtable, vmc_mtable);
```

Attach tables to **nc_machine** object:

```
if (ok1) then vmc.gtable := vmc_gtable;
if (ok2) then vmc.mtable := vmc_mtable;
```

Machine Dependent Tasks

Machine dependent tasks are those unique to a specific machine and/or a machine controller. These can be related to the machine configurations or tooling data. Custom G and M codes are used to control optional peripherals, and to support non-standard subroutines and canned cycles.

Tool Changers

The most common machine dependent tasks are those relating to tool changers and external tooling databases. We have already seen in Chapter 2, “Object-Oriented Programming in SIL” about how the same M code (**M6** - tool change) executes completely different tasks because of variations in tool changing mechanisms. Chapter 7, “Modeling NC Tooling”, illustrates the differences in tool changers between turning machines (turrets) and machining centers (chain type tool magazines).

For a machining center, a typical tool change sequence usually consists of the following steps:

1. Move machine axes to tool change position (usually “home” position.

2. Search tool from tool magazine by indexing the tool chain to the specified station (most machines use the shortest path to determine forward or reverse indexing).
3. Exchange tool between tool magazine and machine spindle.
4. Update tooling data, if applicable (see Example 8.3).

For a turning machine with rotating turret, the typical tool change sequence is

1. Index turret to specified station.
2. Update tooling data, if applicable (see Example 8.4).

Soft Machines includes built-in routines for indexing chain-type tool magazines (**ncv_index_tc**) and rotating turrets (**ncv_index_turret**):

```
task ncv_index_tc(m: nc_machine; forward: boolean);
task ncv_index_tc(m: nc_machine; target_station: integer);

task ncv_index_turret(m: nc_machine; forward: boolean);
task ncv_index_turret(m: nc_machine;
                      target_station: integer);
```

where **forward** is **TRUE** when indexing *forward*, **FALSE** when indexing *backward;* and **target_station** is the specified station number *(shortest path used).*

Example 8.3

Step 1: Construct task for exchanging tool between cutter and magazine:

```
task kt_moduline_swap_tool(m: nc_machine);
var arm, extender, pocket, spindle_flange: shape;
   stn_no: integer;
   th1, th2: tool_holder;
   td_tmp: kt_tool_data;
   sh: shape;
```

continued on next page

Example 8.3 (continued)

```
begin
   wait(kt_got_tool);      { Wait until tool search is completed }
   stn_no := ncv_current_station(m); { Find current station no }
   spindle_flange := wlkup(name(m) * '_FLANGE');
                              { Find tool changer objects }
   extender := wlkup(name(m) *
                          '/LINK3/T_CHANGER/SLIDER');
   pocket := wlkup(name(m) *
                          '/LINK3/T_CHANGER/POCKET');
   arm := wlkup(name(m) *
                          '/LINK3/T_CHANGER/SLIDER/ARM');

  { Set speed and acceleration }
   set_speed_acc(extender,
                    mk_speed_and_acc(100.,90.,750.,750.));
   set_speed_acc(arm,
                    mk_speed_and_acc(100.,90.,750.,750.));
   set_speed_acc(pocket,
                    mk_speed_and_acc(100.,90.,750.,750.));

   th2 := get_active_holder(m); { Ready holder from magazine }
   if not(nul(th2)) then
      begin
         unmount_th(m, stn_no); affix(th2, pocket);
      end;
   moveto_s(pocket, mk_ypr(-90.,0.,0.) rel pose(pocket));
   moveto_s(extender, mk_ypr(0.,0.,-90.) rel pose(extender));

  { Mount holder from magazine onto tool changer arm }
   if not(nul(th2)) then unaffix(th2, pocket);
   if not(nul(th2)) then affix(th2, arm);

   th1 := get_holder_on_flange(m);
               { Mount holder from spindle to arm}
   if not(nul(th1)) then
      begin
         unaffix(th1, spindle_flange); affix(th1, arm);
      end;
```

continued on next page

Example 8.3 (continued)

```
    { Extend arm, then rotate 180 degrees }
     moveto_s(extender, mk_crt(0.,0., 15.) rel pose(extender));
     moveto_s(arm, mk_ypr(0.,0.,180.) rel pose(arm));

    { Position holders onto machine spindle and tool magazine
      pocket }
     moveto_s(extender, mk_crt(0.,0., -15.) rel pose(extender));
     if not(nul(th1)) then
        begin
           unaffix(arm,th1); affix(th1,pocket);
        end;
     if not(nul(th2)) then
        begin
           unaffix(arm,th2); affix(th2, spindle_flange);
        end;

    { Move arm and pocket to original positions }
     moveto_s(extender, mk_ypr(0.,0.,90.) rel pose(extender));
     moveto_s(pocket, mk_ypr(90.,0.,0.) rel pose(pocket));
     if not(nul(th1)) then
        begin
           unaffix(th1, pocket); mount_th(th1, m, stn_no);
        end;
     delay(kt_moduline_tool_change_interval);

    { Update tool library database }
     td_tmp := kt_get_tool_data(m, stn_no);
     kt_put_tool_data(m, stn_no, kt_moduline_active_tdata);
     kt_moduline_active_tdata :=
     copy(td_tmp as_type ob) as_type kt_tool_data;
     signal(kt_got_tool);
  end;
```

Step 2: Construct task for indexing tool magazine:

```
  task kt_moduline_index_tc(m: nc_machine; tcode: integer);
  begin
     wait(kt_got_tool);
                  { Wait for completion of swap tool sequence }
```

continued on next page

Example 8.3 (continued)

```
    ncv_index_tc(m, tcode);
    signal(kt_got_tool); { Signal tool changer arm }
  end;
```

Step 3: Construct task for tool search using tooling database

```
  task kt_search_tool(m: nc_machine; tcode: integer):
  boolean;
  var i, tool_stn: integer;got_my_tool: boolean;
    tl: tool_lib;
    tool_data: darray of kt_tool_data;
      { Tool database structure }
    p: pnt2di;
  begin
    got_my_tool := false;
    tl := specialize_to(wlkup(m.tlib), tool_lib);

   { Is tool parameters defined in tool lib? If yes, index tool changer }
    if (type_of(tl.aux) =
    type_of(kt_moduline_tool_data as_type universal)) then
    begin
      tool_data := tl.aux as_type darray of kt_tool_data;
      for i := 0 to length(tool_data)-1 do
      begin
        if (tool_data[i].tool_id = tcode) then begin
        tool_stn := tool_data[i].stn_no; got_my_tool:= true;
  end;
      end;
    end;
    if (got_my_tool) then start("kt_moduline_index_tc, m,
                                tool_stn);
    kt_search_tool := got_my_tool;
  end;
```

Step 4: Construct function for retrieving tool offsets information

```
   { Get tool length offset from database }
  function kt_get_tlo(m:nc_machine; g:gcode_info;
  pos_offset:boolean): real;
```

continued on next page

Example 8.3 (continued)

```
var   offset: real;
      tl: tool_lib;
      aotd: darray of kt_tool_data;

begin
   offset := 0.;
   tl := specialize_to(wlkup(m.tlib), tool_lib);
   if not(nul(tl)) then
      begin
        if (type_of(tl.aux) = type_of(aotd as_type universal))
          then
          begin
            aotd := tl.aux as_type darray of kt_tool_data;
            for i := 0 to length(aotd)-1 do
            begin
              if aotd[i].tool_id = g.t then begin
              if (pos_offset)
              then offset := aotd[i].preset * current_unit
              else offset := -aotd[i].preset * current_unit;
            end;
          end;
      end;
   kt_get_tlo := offset;
end;

{ Map tool length offset to Z axis of machine }
task kt_tlo(m: nc_machine; g: gcode_info; pos_offset:
              boolean);
var   axes: darray of real;
      j: integer;
      tlo: real;
begin
   axes := array_create(real,6);
   for j := 0 to 6 do axes[j] := kt_tool_offsets[j];
   tlo := kt_get_tlo(m, g, pos_offset); { Grep TLO data from
                                          database }
   axes[abs(m.z_link)] := tlo;
```

continued on next page

Example 8.3 (continued)

```
    kt_tool_offsets :=
    mk_jv(axes[1],axes[2],axes[3],axes[4],axes[5],axes[6]);
end;
```

Step 5: Combine Steps 1 to 4 to construct tool change simulation

Tool change simulation consists of the following sequence:

- Start tool search (**kt_moduline_search_tool**);
- Move Y and Z axes (LINK4 and LINK5) to tool change position;
- When tool search is completed, exchange tool between machine spindle and tool magazine (**kt_swap_tool**);
- Reset cutter traces if necessary;
- Set tool length offsets if necessary.

```
task kt_moduline_tool_change(m: nc_machine; g:
gcode_info);
var cjv, tool_change_jv: jv;
begin
   if (g.t > 0) then kt_moduline_search_tool(m, g);
   cjv := c_jv(m);
   tool_change_jv := home_of(name(m));
   if not(aequal(cjv, tool_change_jv)) then { Move tool change
                                              position }
      begin
         cjv.j4 := tool_change_jv.j4; moveto(m, cjv);
         cjv.j5 := tool_change_jv.j5; moveto(m, cjv);
      end;
   if (ncv_trace_mode) then
      begin
         if really_in_world(ncv_trace_object) then
            stop_cutter_trace(ncv_trace_object);
      end;
   if (g.p > 0) then kt_tlo(m, g, true);  { Load tool length offsets }
   kt_moduline_swap_tool(m);              { Swap tool }
   if (ncv_trace_mode) then               { Reset cutter traces for
                                            new cutter }
   if really_in_world(ncv_trace_object) then
      start_cutter_trace(m, ncv_trace_object);
end;
```

Example 8.4

Index turret to specified station number:

```
task ge2000t_tool_change(nc: nc_machine;
target_station_no: integer);
begin
   if (is_tool_lib(nc.tlib)) then
      ncv_index_turret(nc, target_station_no)
   else
      writeln('index_current_station: No tool lib mounted on
                  machine');
end;
```

Forward Kinematics Moves

Complex 5 and 6 axes machines require G code move statements be resolved into joint vectors when executing the moves (forward kinematics moves). Chapter 6, “Modeling NC Machines”, and Chapter 7, “Modeling NC Tooling”, describe how the ***X, Y, Z, …*** parameters in a G code statement can be mapped to joint vector convention (**ncv_axes_to_jv**), and how work coordinate systems and cutter offsets must be defined in joint space.

In developing SIL tasks to perform forward kinematics moves, we must consider the following:

- Definition of work coordinates in joint vectors (Example 8.5).
- Definition of cutter offsets in joint vectors.
- Execution of move commands with respect to the active work coordinate system (Example 8.6).

Example 8.5

Given a 6-axis **machining_center kt_moduline** (Kearney and Tracker Moduline), suppose we want to set the current joint position (**cjv**) of the machine as reference for a work coordinate system (**G54** to **G59**). We set the subfield **kt_moduline.ref_jv** as follows:

For **G54** **kt_moduline.ref_jv[0] := cjv(kt_moduline);**
For **G55** **kt_moduline.ref_jv[1] := cjv(kt_moduline);**
For **G56** **kt_moduline.ref_jv[2] := cjv(kt_moduline);**
For **G57** **kt_moduline.ref_jv[3] := cjv(kt_moduline);**
For **G58** **kt_moduline.ref_jv[4] := cjv(kt_moduline);**
For **G59** **kt_moduline.ref_jv[5] := cjv(kt_moduline);**

We can write a SIL procedure as follows:

```
procedure kt_set_ref(mc: machining_center; coord_sys:
integer);
begin
   if ((coord_sys >= 54) and (coord_sys <= 59)) then
      mc.refjv[coord_sys-54] := cjv(mc);
end;
```

Example 8.6

```
task kt_moveto(nc: nc_machine; g: gcode_info):
gcode_status;
var msg: string;
   p: point;
   coord: integer;
   reference: jv;
   mc: machining_center;
begin
   msg := null_string;
   if (g.got_g) then                    { Check for G0 or G1 }
   begin
      if member(0, g.gcode) then        { G0 - Rapid Move }
      begin
         use_js_planner(name(nc), "non_sync_js);
                                        { Set path planner }
```

continued on next page

Example 8.6 (continued)

```
        if not(ncv_prog_feed_override) then
              ncv_set_rapid(nc);
    { Machine in positioning mode—this sets up collision checks }
        positioning_mode(nc);
        msg := '{ G0 } use_js_planner(name(kt_moduline),
            "non_sync_js); ';
      end;
      if member(1, g.gcode) then { G1 - Linear interpolation }
        begin
          use_js_planner(name(nc), "trapfly_js);
          msg := '{ G1 } use_js_planner(name(kt_moduline),
                                  "trapfly); ';
          if not(ncv_prog_feed_override) then
                ncv_set_feedrate(nc, g);
        end;

      if (nc.status.programming = 'absolute') then
                          { Absolute moves }
        begin
          if member(53, g.gcode) then { G53, use machine base
                                        coordinates }
          begin
            reference := kt_moduline_base_jv;
            msg := msg * 'ncv_moveto(kt_moduline,
                  kt_moduline_base_jv)';
          end
      begin
        use_js_planner(name(nc), “non_sync_js);
                              { Set path planner }
      else
        begin
          coord := abs(g.gcode[12]) - 54;
                { g.gcode[12] defines work coordinates }
          mc := specialize_to(nc, machining_center);
          reference := mc.ref_jv[coord] + kt_tool_offsets;
        end;
      end
```

continued on next page

Example 8.6 (continued)

```
        else
          reference := c_jv(nc);
      end;
      ncv_moveto(nc, g, reference);
      kt_moveto := mk_gcode_status(true, g.stmt_no, msg);
    end;
```

Canned Cycles

A **canned cycle** is a G code function designed to simplify commands for command machining operations (drilling, boring, threading, etc.). It defines a preset series of operations which direct-machine-axis movement causes a spindle operation to complete a machining cycle. Canned cycles can greatly reduce the number of part program statements, since one canned cycle statement may do the equivalent of many individual conventionally programmed statements.

Common canned cycles are defined by the G codes 81 to 89:

Code	Movement In	Dwell at Bottom	Spindle at Bottom	Movement Out	Typical Usage
G81	Feed	--	--	Rapid	Drill, Spot Drill
G82	Feed	Yes	--	Rapid	Drill, Counterbore
G83	Intermittent	--	--	Rapid	Deep Hole
G84	Spindle Forward Feed	--	Rev	Feed	Tap
G85	Feed	--	--	Feed	Bore

Table 8-3 Common canned cycle codes

Code	Movement In	Dwell at Bottom	Spindle at Bottom	Movement Out	Typical Usage
G86	Start Spindle, Feed	--	Stop	Rapid	Bore
G87	Start Spindle, Feed	--	Stop	Manual	Bore
G88	Start Spindle, Feed	Yes	Stop	Manual	Bore
G89	Feed	Yes	--	Feed	Bore

Table 8-3 Common canned cycle codes (continued)

To simulate canned cycles, we must construct a series of SIL tasks corresponding to the series of operations defined by the G code (see Example 8.7). The default G code table in Soft Machines provides built-in canned cycles (**G80** - **G81**) for common 3-axis operations (inverse kinematics moves only).

Example 8.7

The canned cycle **G81** (spot drill) for the FANUC controller consists of the following sequences:

1. Move cutter to initial point (rapid feed);
2. Move cutter to retract level ("return" point, rapid feed);
3. Drill to specified depth (programmed feed rate);
4. Retract cutter to retract level (rapid);
5. Move to next drill position.

continued on next page

Example 8.7 (continued)

The G code statement has the syntax:

G81X--Y--Z--R--L--F--

where: **X** and **Y** define the drill position
Z defines the drill depth
R defines the retract level
L defines how many times to repeat the operation
F defines the feed rate.

Also, the G codes **G98** and **G99** set the retract level: **G98** for retracting to **initial level**, **G99** for level defined by the **R** parameter.

Step 1: Set up return level for canned cycle.

```
procedure ncv_set_r_level(nc: nc_machine; g: gcode_info);
var loi: list of integer;
begin
  loi := get_current_gcodes(g);
              { G98 - return to initial level, G99 - return to R level }
  if (member(98, loi)) then ncv_r_level := ncv_init_level;
  if (member(99, loi)) then
     begin
        ncv_r_level := g.r;
        ncv_got_r := true;
     end;
end;

procedure ncv_set_init_level(nc: nc_machine; g:
                                        gcode_info);
var f: frame;
begin
  f := (pose(nc.move_handle) in_frame pose(nc.ref));
  ncv_init_level := f.ztr/current_unit;
end;
```

Step 2: Construct task for canned cycle.

```
task spot_drilling(nc: nc_machine; g: gcode_info):
gcode_status;
```

continued on next page

Example 8.7 (continued)

```
var msg: string;
   j, k: integer;
   p: point;
begin
   ncv_set_init_level(nc,g);
   ncv_set_r_level(nc,g);
   if g.got_l then k := g.l
   else k := 1; { Got L? If yes, repeat L times }
   for j := 0 to k-1 do
   begin
      if not(ncv_prog_feed_override) then
         ncv_set_rapid(nc);
  { Operation 1 - moveto initial point }
      if (nc.status.programming = 'absolute') then
         ncv_moveto(nc, g.xc, g.yc, ncv_init_level)
         else ncv_moveincr(nc, g.xc, g.yc, 0.);
      ncv_init_jv := c_jv(nc);{ Initial jv of canned cycle }
      p := ncv_get_xyz(nc);
  { Operation 2 - moveto point R }
      ncv_moveto(nc, p.xc, p.yc, ncv_r_level);
      ncv_return_jv := c_jv(nc);
      if (g.f = 0) then
         ncv_report_error(nc, g, 'spot_drilling - feed rate not
                                  specified. ')
      else
         if not(ncv_prog_feed_override) then
            ncv_set_feedrate(nc, g);

      ncv_moveto(nc, p.xc, p.yc, g.zc); { Operation 3 - drill }

      if not(ncv_prog_feed_override) then
         ncv_set_rapid(nc);{ Operation 4 - return }
      if (ncv_init_point_return) then
         moveto(nc, ncv_init_jv)
      else
         moveto(nc, ncv_return_jv);
   end;
   spot_drilling := mk_gcode_status(true, g.stmt_no, msg);
end;
```

In some controllers, a cycle is initialized by setting the canned cycles G codes (**G81** to **G89**). The active canned cycle is then called by other G codes (**G98**, **G99** …, etc.). In such cases, we establish the active canned cycle by setting the global variable **canned_cycle** (type **closure**) whenever a cycle is initialized. The active canned cycle can then be executed by other call functions (see Example 8.8).

Example 8.8

In Soft Machines, the following canned cycles are included for 3-axis milling machines or machining centers:

```
G74    task l_hand_tapping(nc: nc_machine; g:
                              gcode_info): gcode_status;
G76    task fine_boring(nc: nc_machine; g: gcode_info):
                              gcode_status;
G81    task spot_drilling(nc: nc_machine; g: gcode_info):
                              gcode_status;
G82    task counter_boring(nc: nc_machine; g:
                              gcode_info): gcode_status;
G83    task peck_drilling(nc: nc_machine; g: gcode_info):
                              gcode_status;
G84    task tapping(nc: nc_machine; g: gcode_info):
                              gcode_status;
G85    task boring(nc: nc_machine; g: gcode_info):
                              gcode_status;
G86    task rapid_boring(nc: nc_machine; g: gcode_info):
                              gcode_status;
```

We declare the following closures:

```
left_hand_tapping_cl == mk_closure("l_hand_tapping,
          task(gcode_status, nc_machine, gcode_info));
fine_boring == mk_closure("fine_boring, task(gcode_status,
                          nc_machine, gcode_info));
                              .
                              .
                              .
```

continued on next page

Example 8.8 (continued)

The G code tasks will look as follows:

```
task g81(nc: nc_machine; g: gcode_info): gcode_status;
begin
   canned_cycle := spot_drilling_cl; { Set active canned cycle }
   g81 := canned_cycle(nc, g);       { Execute canned cycle }
end;
```

Other G codes can call the active canned cycle as follows:

```
task g98(nc: nc_machine; g: gcode_info): gcode_status;
var msg: string;
begin
   ncv_init_point_return := true; { Initial level return, true for
                                    G98, false for G99 }
   msg := 'ncv_init_point_return := true;';
                                  { Execute canned cycle }
   if not(nul(canned_cycle)) then
      g98 := canned_cycle(nc,g);
end;
```

Constructing and Customizing G and M Tables

We have learned how to utilize default tables as a basis to construct a machine-specific NC simulator, and to use built-in Soft Machines routines to develop machine-specific tasks. Custom G and M tables can be built by mixing custom-developed, machine-specific routines with standard G and M codes then attaching them to an **nc_machine** object.

Grouping G Codes

There is a standard set of rules in the execution of NC part program statements:

1. There are two different types of G codes:
   a. Retained G codes (modal)
   b. One shot G codes (non-modal).

2. G codes are divided into several different groups.
3. Multiple G codes may be programmed in one part program statement.
4. Only one G code from each modal group and one non-modal G code can be programmed in the same statement.

Example 8.9
Valid = **G01, G41, G95**
Invalid = **G00, G01, G40, G41**
G00/G01 and **G40/G41** are from the same groups (can cancel each other).

5. A retained G code from one group remains active until another from the same group is programmed in a subsequent statement.
6. Non-modal (one shot) G codes must be programmed in every block when required.
7. All M codes are considered non-modal.
8. A “Power-Up” or “Reset” operation re-initializes all the G codes.

In Soft Machines, a G code table is defined as an array of type **g_functions**:

```
type gcode_closure =
                tclosure(gcode_status, nc_machine, gcode_info);

  type g_function = lrecord
                        group: integer;
                        cl: gcode_closure;
                        end;;
```

For every G code represented by a task closure of type **gcode_closure**, we assign a **group** number and attach it to the group field of the type **g_function.** To follow the rules, we adopt the following conventions for **g_function.group**:

1. All non-modal (one shot) G codes belong to Group 0.

2. Group numbers for each modal group are determined by the NC part programmer's manual. When unavailable, we use the groups defined in **default_gtable**.
3. Each group has a default (power-up configuration) G code.
4. A positive (+ve) value in **g_function.group** sets the G code and executes **g_function.gcode_closure**, a negative value sets the G code but does not execute any task.

Group numbers for the default G table is as follows (* = default):

Code	Grp	Description
G0	1*	Rapid Transverse
G1	1	Linear Interpolation
G2	1	Circular Interpolation CW
G3	1	Circular Interpolation CCW
G4	0	Program Delay
G8	9*	Disable Acceleration / Deceleration Control
G9	9	Enable Acceleration / Deceleration Control
G17	2*	Plane Selection XY
G18	2	Plane Selection ZX
G19	2	Plane Selection YZ
G28	0	Move axes to HOME position
G40	7*	Radius Compensation OFF
G41	7	Cutter Compensation LEFT
G42	7	Cutter Compensation RIGHT
G53	0	Move wrt Machine Coordinates

Table 8-4 Group numbers for the default G table

Code	Grp	Description
G54	12*	Move wrt Work Coordinates 1
G55	12	Move wrt Work Coordinates 2
G56	12	Move wrt Work Coordinates 3
G57	12	Move wrt Work Coordinates 4
G58	12	Move wrt Work Coordinates 5
G59	12	Move wrt Work Coordinates 6
G60	13	Single Direction Positioning
G61	13	Exact Stop Mode
G62	13	Corner Radius Override
G63	13	Tapping Mode
G64	13*	Cutting Mode
G68	16	Coordinate System Rotation
G69	16	Coordinate System Rotation
G70	6*	Inch Programming
G71	6	Metric (mm) Programming
G73	9	Canned cycle - Rapid Drilling
G74	9	Canned Cycle - Left Hand Tapping
G76	9	Canned Cycle - Fine Boring
G80	9*	Canned Cycle Cancel
G81	9	Canned Cycle - Spot Drilling
G82	9	Canned Cycle - Counter Boring

Table 8-4 Group numbers for the default G table (continued)

Code	Grp	Description
G83	9	Canned Cycle - Peck Drilling
G84	9	Canned Cycle - Tapping
G85	9	Canned Cycle - Boring
G86	9	Canned Cycle - Rapid Boring
G90	10*	Absolute Dimension Input
G91	10	Incremental Dimension Input
G92	0	Preload Machine Registers
G93	17	Inverse Time Feedrate
G94	17*	Inch or mm / min Feedrate
G95	17	Inch or mm / rev Feedrate
G96	17	Constant Surface Feedrate
G97	17	Revolution / min (rpm)
G98	10	Initial Level Return TRUE
G99	10*	Initial Level Return FALSE

Table 8-4 Group numbers for the default G table (continued)

To customize a G code table, we use the procedure **add_gcode**:

```
procedure add_gcode(code, group: integer;
          gcode_closure_id: id; table: array_of(g_function));
```

where

code is the G code number
group is the group number
gcode_closure_id is an **id** pointing to the **gcode_closure** performing the simulation
table is the G code table.

Similarly, the procedure **add_mcode** adds M code closures to an M code table:

```
procedure add_mcode(code: integer; task_id: id;
                    table: array_of(gcode_closure));
```

Example 8.10 shows how **add_gcode** and **add_mcode** are used to construct a G code table using both built-in and custom **gcode_closures**.

Example 8.10

Add built in G codes:

```
add_gcode(4, 0, "g4, kt_gtable);          { Program Delay }
add_gcode(17, 2, "g17, kt_gtable);        { XY Plane }
add_gcode(18, 2, "g18, kt_gtable);        { ZX Plane }
add_gcode(19, 2, "g19, kt_gtable);        { YZ Plane }
add_gcode(28, 0, "g28, kt_gtable);        { Reference Point Return
                                            (Home) }
add_gcode(40, 7, "g40, kt_gtable);        { Radius Compensation Off }
add_gcode(41, 7, "g41, kt_gtable);        { Cutter Compensation Left }
add_gcode(42, 7, "g42, kt_gtable);        { Cutter Compensation Right }
add_gcode(61, 15, "g61, kt_gtable);       { Exact Stop Mode }
add_gcode(62, 15, "g62, kt_gtable);       { Corner Override Mode }
add_gcode(63, 15, "g63, kt_gtable);       { Tapping Mode }
add_gcode(64, 15, "g64, kt_gtable);       { Cutting Mode }
add_gcode(70, 6, "g70, kt_gtable);        { Inch Programming }
add_gcode(71, 6, "g71, kt_gtable);        { mm Programming }
add_gcode(90, 3, "g90, kt_gtable);        { Absolute programming
                                            mode }
add_gcode(91, 3, "g91, kt_gtable);        { Incremental programming
                                            mode }
add_gcode(93, 5, "g93, kt_gtable);        { Inverse time feedrate }
add_gcode(94, 5, "g94, kt_gtable);        { Feed per min }
add_gcode(95, 5, "g95, kt_gtable);        { Feed per rev }
add_gcode(96, 17, "g96, kt_gtable);       { Constant surface feed }
add_gcode(97, 17, "g97, kt_gtable);       { Constant surface feed
                                            cancel }
```

continued on next page

Example 8.10 (continued)

Add custom G codes (from Example 8.6)

```
add_gcode(0, 1, "kt_moveto, kt_gtable);      { G0 - rapid }
add_gcode(1, 1, "kt_moveto, kt_gtable);      { G1 - linear
                                               interpolation }
```

NOTE The same **gcode_closure** can be called by more than one G code. Other custom G codes can be added in a similar fashion.

Add built in M codes from default M code table:

```
copy_mtable(default_mtable, kt_mtable);
```

Add M custom codes:

```
add_mcode(6, "kt_m6, kt_mtable);      { M6 tool change }
add_mcode(90, "kt_m90, kt_mtable);    { M90 activate left table }
add_mcode(91, "kt_m91, kt_mtable);    { M91 activate right table }
```


Error Logging and Reporting

Soft Machines provides error logging and facilities in two forms:

- Error messages can be displayed either during the simulation, or saved as a text file for later viewing.
- Graphics animation files (movies) can be saved, errors such as collisions highlights are saved with movies.

Error Log

Soft Machines uses the command **ncv_report_error** for reporting of error messages:

procedure ncv_report_error (nc: nc_machine; g: gcode_info; err_msg: string);

where	
input:	**nc** is the current NC machine; **g** contains the G code statement data structure; **err_msg** is the error message to be displayed.
output:	Name of NC machine; Statement number at which error occurs; Error message(s).

When the user requests an error log file from the Simulation Setup panel, **ncv_report_error** sends all error messages to the specified log file, in addition to displaying the error messages in the *SIL Window*.

ncv_report_error should be called whenever an error condition occurs.

Recording Movies

Movie recording is conducted automatically through selections in the Movies panel. It is not necessary to develop special routines for saving graphics animation to Soft Machines movie files.

Chapter 9

Constructing the G Code Translator

This chapter explains the following topics:

- ➢ *Architecture of a G Code Translator*
- ➢ *Converting G Code into SIL Data Type*
  - ■ gcode_info Data Type
  - ■ G Code Reader
- ➢ *Executing G and M Codes*
- ➢ *Subroutines and Synchronized Cutting*

In previous chapters, an NC simulator was defined as a software module consisting of the following components:

- ■ Specialized object class consisting of the kinematics model of an NC machine, machine pendant panel and NC-related parameters (Chapters 5 and 6).
- ■ Specialized objects for NC tooling (Chapter 7).
- ■ G and M code tables containing SIL routines (task closures) simulating NC functions (machine dependent and machine independent) (Chapter 8).
- ■ G code translator to translate part programs statements into calls from the G and M tables, and execute the simulation.

This chapter describes the process of constructing a G code translator and attaching it to an **nc_machine** object, and how this translator is used to execute an NC simulation.

Architecture of a G Code Translator

Figure 9-1 provides a schematic view of how input data (G code statements) is converted into SIL calls in the simulation of an NC part program.

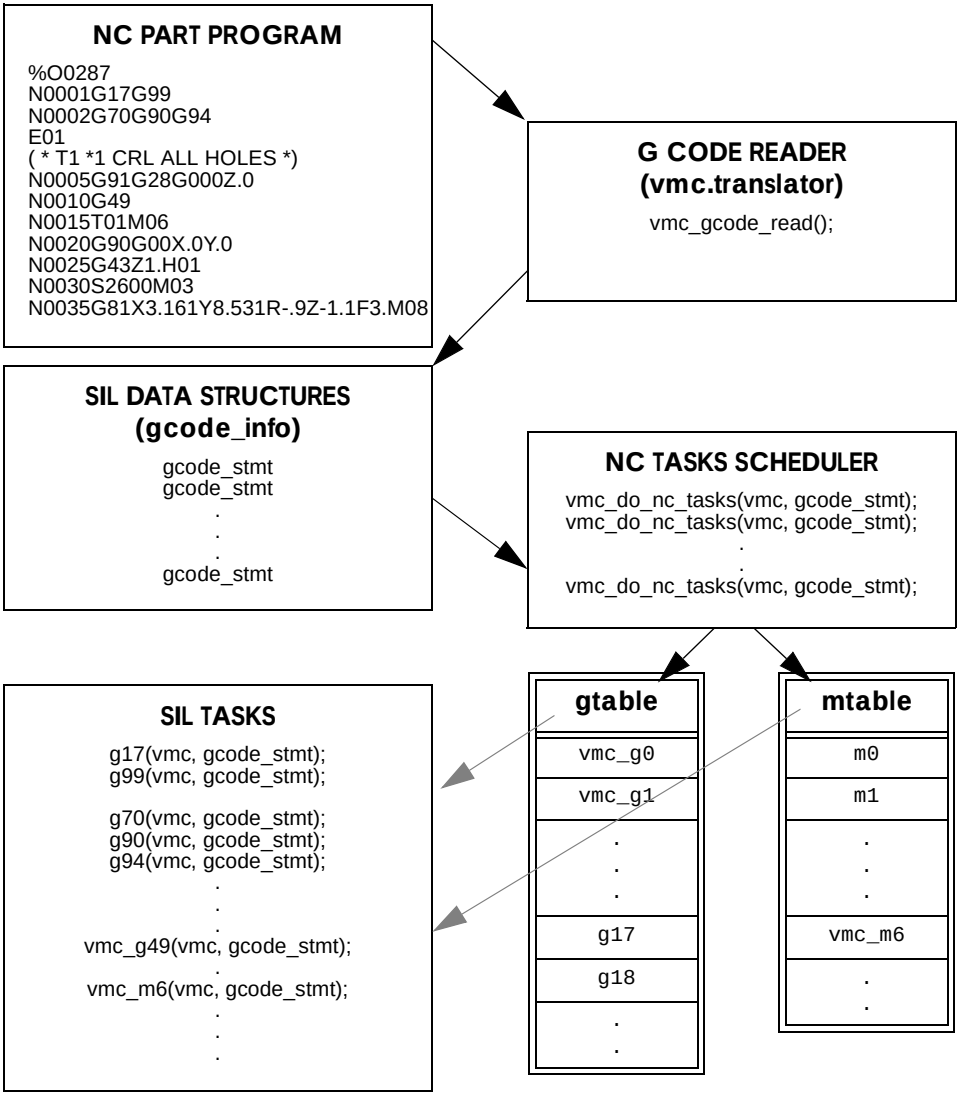


Figure 9-1 Data flow for a G code translator

A G code translator consists of

1. A reader that converts each G code statement into the SIL data type **gcode_info**.
2. A task scheduler that:
   - reads the **gcode_info** date type and calls out the relevant task closures from the G and M tables
   - executes the tasks closures corresponding to each part program statement.

Developing the G code translator is the last step in the completion of the development of the NC simulator.

Converting G Code into SIL Data Type

gcode_info Data Type

In Soft Machines, all G code statements are represented internally using the data type **gcode_info**:

```
type gcode_info = lrecord
    gcode: array_of(integer);
    mcode: list_of(integer);
    gots: integer;
    gots2: integer;
    input: string;
    stmt_name: string;
    stmt_no: integer;
    xc:real; yc:real; zc:real;
    ic:real; jc:real; kc:real; u:real; v:real; w:real;
    a:real; b:real; c:real;
    f:real; e:real; q:real; r:real;
    l:integer; t:integer; s:integer; p:integer;
    multi_r: array_of(real);
```

continued on next page

```
        d:integer;
        colon: integer;
        at_sign: multi_r_record;
        h: integer;
    end;;
```

This data type can represent G code statements in the forms:

N_G_G_...X_Y_Z_I_J_K_A_B_C_I_J_K_U_V_W_F_E_Q_R_L_T_S_P_D_H_M_M_…

N_G_R01_R02_R03_...

Each field can either represent input values (**G** and **M** codes in statement, parameters for **X, Y, Z, I, J, K**, …, etc.), or the two "**gots**" fields, which contain boolean bit fields which log the status of the input statement. Each input field has a corresponding **got** field. For example, if a statement contains **N**, **G**, **X** and **Y**:

N0020G90G00X0.Y0.

The **got_n**, **got_g**, **got_x**, and **got_y** fields will be set to **TRUE**, other gots fields (**got_z**, **got_m**, **…**, etc.) will be **FALSE**.

Description of each field is as follows:

FIELD	TYPE	DESCRIPTION
gcode	**array of integer**	G code field, each array element contains the value of each G code group (see "Grouping G Codes" on page 8-23).
mcode	**list of integer**	M code fields.
gots	**integer**	Bit fields denoting input status: bit0 =**TRUE** if **X** exists (**gcode_info.got_x = TRUE**) bit1 = **TRUE** if **Y** exists (**gcode_info.got_y = TRUE**), etc.

Table 9-1 **gcode_info** fields

FIELD	TYPE	DESCRIPTION
gots2	**integer**	More bit fields denoting input status, see **gots**.
input	**string**	Original G code statement.
stmt_name	**string**	Name of statement (if **N** field is string).
stmt_no	**integer**	Statement number (if **N** field is integer).
xc, yc, zc, ic, jc, kc, u, v, w	**real**	Fields for **X**, **Y**, **Z**, **I**, **J**, **K**, **U**, **V**, **W**.
f, e, q, r	**real**	Fields for **F**, **E**, **Q**, **R**.
l, t, s, p	**integer**	Fields for **L**, **T**, **S**, **P**.
multi_r	**array of integer**	Fields for **R01**, **R02**, **R03**, **…**, etc.
d	**integer**	**D** field.
colon	**integer**	Colon (**:**) field.
at_sign	**multi_r_record**	For @_ _ **R**_ **R**_ (currently not used).
h	**integer**	**H** field.

Table 9-1 **gcode_info** fields (continued)

G Code Reader

A G code reader converts each input statement to **gcode_info**. In essence, the reader maps every field present in a G code statement to the corresponding field in **gcode_info**. The fields **gots** and **gots2** are also updated for each input field.

Reading a G Code Statement

To read a complete G code statement, we parse all the relevant fields that may exist for a particular controller/machine combination. The global **gcode_stmt** can then be passed to the task scheduler for execution (see Example 9.1).

Example 9.1

Suppose the G code input for machine vmc consists of statements in the following formats:

N_G_X_Y_Z_I_J_K_F_S_T_M_D_H_R_P_
or **:_G_X_Y_Z_I_J_K_F_S_T_M_D_H_R_P_**

We declare the procedure **vmc_handle_stmt** to read the input statement contained in the global variable **gc_line**:

```
procedure vmc_handle_stmt(nc: nc_machine);
var new_gc_data: ^gc_data;
begin
   gcode_stmt.gots := 0;              { Reset gots }
   gcode_stmt.gots2 := 0;
   gc_index := 0;
   gc_len := length(gc_line);

   { Parse input statement and put the information in gc_data }
   new_gc_data := jill_gc_tranx(copy_cstring(gc_line))
                        as_type ^gc_data;
   handle_g(nc, new_gc_data);     { Grab G code }
   handle_m(nc, new_gc_data);     { Grab M code }
   make_gcode_stmt(new_gc_data);
                              { Construct G code statement }
end;
```

jill_gc_tranx is a parser function. It transfers the input statement into a data structure, **gc_data**. While **jill_gc_tranx()** takes care of the generic input of G and M codes (for example, N10G01X12.5), the function **gc_get_real()** takes care of some special cases, like **G91.2** and **M6.2**. The result is stored in the global **gcode_stmt**.

To execute the statement, we use the task **vmc_do_nc_tasks** (explained later):

```
start("vmc_do_nc_tasks, vmc, gcode_stmt);
```

Reading a G Code File

In the simplest sense, reading an entire part program (G code file) means reading and executing the program statements line-by-line until the end of the input file ("one pass" approach shown in Example 9.3). Handling input files with more complicated syntax, such as those required for multiple turrets (synchronized cutting) and programs containing subroutines, require a "multiple pass" approach. This will be explained in a later section.

Example 9.2

To continue with Example 9.2, we construct the G code reader as follows:

Step 1: Initialize G code defaults

```
vmc_default_mcodes == emptylist(integer);
vmc_default_gcodes == array_create(integer, 20);
                                        { G groups 0 to 20 }

function vmc_set_gcode_defaults(): gcode_info;
begin

   vmc_default_gcodes[0] := -999;
                    { Grp 0 default - Currently not used }

   vmc_default_gcodes[1] := -1;
                    { Grp 1 default - G1 linear interpolation }

   vmc_default_gcodes[2] := 17;
                    { Grp 2 default - G17 XY Plane }

   vmc_default_gcodes[3] := 90;
                    { Grp 3 default - G90 Absolute programming }

   vmc_default_gcodes[4] := -999;
                    { Grp 4 default - Currently not used }

   vmc_default_gcodes[5] := 94;
                    { Grp 5 default - G94 Feed ipm or mm/min }

   vmc_default_gcodes[6] := 70;
                      { Grp 6 default - G70 Inch Input }
```

continued on next page

Example 9.2 (continued)

```
vmc_default_gcodes[7] := -40;
                { Grp 7 default - G40 No radius compensation }

vmc_default_gcodes[8] := -49;        {
                 Grp 8 default - G43 No tool length offset }

vmc_default_gcodes[9] := 80;
                { Grp 9 default - G80 No active canned cycles }

vmc_default_gcodes[10] := -98;
                { Grp 10 default - G98 Canned cycle level
                return }

vmc_default_gcodes[11] := -50;
                { Grp 11 default - G50 No scaling }

vmc_default_gcodes[12] := -54;
                { Grp 12 default - G54 Use Coord Sys 1 }

vmc_default_gcodes[13] := 64;
                { Grp 13 default - G64 Cutting Mode }

vmc_default_gcodes[14] := -67;
                { Grp 14 default - G67 No macro calls }

vmc_default_gcodes[15] := -999;
                { Grp 15 default - Currently not used }

vmc_default_gcodes[16] := -69;
                { Grp 16 default - G69 coord system rotation
                cancel }

vmc_default_gcodes[17] := -97;
                { Grp 17 default - G97 constant surface speed
                cancel }

vmc_default_gcodes[18] := -15;
                { Grp 18 default - G15 Polar coordinates
                cancel }

vmc_default_gcodes[19] := -999;
                  { Group 19 default - Currently not used }
```

continued on next page

Example 9.2 (continued)

```
    vmc_default_gcodes[20] := -999;
                        { Group 20 default - Currently not used }

    vmc_set_gcode_defaults :=
      mk_gcode_info(vmc_default_gcodes,
                        vmc_default_mcodes);
end;
```

Step 2: Initialize global **gcode_stmt**

```
gcode_stmt := vmc_set_gcode_defaults();
```

Step 3: Read part program and execute statements

```
task vmc_gcode_read();
var done: boolean;
begin
  open(gc_file, 'input');
  gcode_stmt.input := null_string;
  done := false;
  if (not(eof(gc_file)) then
    gc_line := read_line(gc_file)
  else
    done := true;
  while (not(done) and (gcode_stmt.stmt_no <=
                        ncv_end_statement)) do
  begin
    vmc_handle_stmt(vmc);
    if (gcode_stmt.stmt_no >= ncv_start_statement) then
    begin
      vmc_do_nc_tasks(vmc, gcode_stmt);
      ncv_update_gcode(gcode_stmt,
                        vmc_modal_groups);
      if find(gc_line, ncv_end_condition) >= 0 then
        done := true;
    end;
    if not(eof(gc_file)) then
      gc_line := read_line(gc_file)
    else
      done := true;
```

continued on next page

Example 9.2 (continued)

```
    end;
    close(gc_file);
  end;
```

To simulate the part program, enter

```
gc_file := mk_file(ncv_part_prog_dir * '/*
<part_prog_name>);
start("vmc_gcode_read);
```

Executing G and M Codes

Example 9.1 and Example 9.2 illustrate how part program statements are converted into **gcode_info** and passed to the task scheduler for execution. In Soft Machines, the NC task scheduler uses **gcode_info** to retrieve task closures from the G and M tables for execution. In a "one pass" scheme, the task scheduler works as follows (see Example 9.3):

- For every G code group (retained G codes **gcode_info.gcode[i]**), look up task closure from G table; execute task closure.
- For every M code in input statement, look up task closure from M table and execute task closure.
- Update machine status.

Example 9.3

The tasks **do_gtask** and **do_mtask** hook up G and M codes with task closures contained in the machine's G and M tables:

```
task do_gtask(code_no: integer; nc: nc_machine; g:
                                          gcode_info);
```

continued on next page

Example 9.3 (continued)

```
var   g_task: gcode_closure;
      g_status: gcode_status;
      msg: string;
begin
   if not(nul(nc.gtable[code_no])) then
   begin
      g_task := nc.gtable[code_no].cl;     { Look up G table }
      g_status := g_task(nc, g);           { Execute task }
   end
   else
   begin                                   { Error invalid G code }
      msg := 'G code '*int2str(code_no)*' not implemented';
      g_status := mk_gcode_status(false, g.stmt_no, msg);
      ncv_report_error(nc, g, 'G code msg);
   end;
end;

task do_mtask(code_no: integer; nc: nc_machine; g:
                                          gcode_info);
var m_task: gcode_closure;
   g_status: gcode_status;
   msg: string;
begin
   if not(nul(nc.mtable[code_no])) then
   begin
      m_task := nc.mtable[code_no];        { Look up M table }
      g_status := m_task(nc, g)            { Execute Task }
   end
   else
   begin                                   { Invalid M code }
      msg := 'G code '*int2str(code_no)*' not implemented';
      g_status := mk_gcode_status(false, g.stmt_no, msg);
      ncv_report_error(nc, g, msg);
   end;
end;
```

continued on next page

Example 9.3 (continued)

The task **vmc_do_gtask** is the NC task scheduler for the machine **vmc**:

```
task vmc_do_nc_tasks(nc: nc_machine; ginfo: gcode_info);
var i, g, m: integer;
begin
   update_gcode_window(ginfo);
   update_gcode_status("vmc_gcodes, ginfo.gcode, 1);
   for i := 0 to (length(ginfo.gcode)-1) do
   begin
      g := ginfo.gcode[i];
      if (g >= 0) then
         do_gtask(g, nc, ginfo);          { Do G code }
   end;
   if (ginfo.got_m) then
      for m in ginfo.mcode do do_mtask(m, nc, ginfo);
                                          { Do M code }
   if (detect_collisions) then
      ncv_report_collisions(nc, ginfo);
   set_machine_status(nc.status);
end;
```

Subroutines and Synchronized Cutting

The “one-pass” approach is inadequate when you want to simulate a more sophisticated machine controller, such as one controlling more than one device at the same time (a multiple turret lathe); or a controller that contains built-in subroutines. Part program statements have to be pre-processed and stored in data blocks before being passed to the task scheduler. The SIL data type **ncv_sync_block** is defined as

```
type ncv_sync_block = lrecord
   nc: nc_machine;
   gwindow: vtranscript;
   block_no: integer;
   gc_list: list of gcode_info;
end;;
```

where

nc is the simulated NC machine.

gwindow is the input statement display window.

block_no is the block number.

gc_list is a list of **gcode_info** contained in the current block.

Using **ncv_sync_block**, part program statements can be divided into data blocks. A data block can contain a G code subroutine. Program statements belonging to separate turrets in a multiple turret machine can be separate and stored in difference **ncv_sync_block**s.

Example 9.4 shows the default task scheduler in Soft Machines.

Example 9.5 shows how **ncv_sync_block** is used to implement subroutine calls.

ncv_sync_block can be employed in the simulation of synchronized cutting for turning machines with multiple turrets. In a typical case, synchronized cutting is conducted as follows:

- Multiple turrets (usually 2 - upper and lower) performed machining simultaneously
- Turrets synchronize by running blocks of G code statements concurrently—one block for each turret
- If one turret completes a block ahead of the other turrets, it waits until all turrets complete their respective data blocks
- All turrets start the next data blocks at the same time.

Figure 9-2, “Synchronized cutting,” on page 9-17 presents a schematic view of a typical part program for synchronized machining. In this example, the G codes **G13** and **G14** select the turrets, and the **P** parameter marks the number for each synchronized block—blocks with the same number are executed concurrently.

To mimic the behavior of the controller, our task scheduler would process the part program as follows:

1. Divide program statements into 2 sets, one for each turret.
2. Divide each set into **ncv_sync_block**s, one for each block number.

3. For both turrets, execute concurrent sync blocks.

Example 9.4

Default NC task scheduler for individual G gcode statements:

```
task default_do_nc_tasks(nc: nc_machine; ginfo:
                                                gcode_info);
var i, g, m: integer;
   los: list of string;
   losh: list of shape;
begin
   if (ginfo.input <> null_string) then
   begin
      for i := 0 to (length(ginfo.gcode)-1) do { Do G code }
      begin
           g := ginfo.gcode[i];
           if (g >= 0) then
                do_gtask(g, nc, ginfo);
      end;
      if (ginfo.got_m) then                    { Do M code }
           for m in ginfo.mcode do do_mtask(m, nc, ginfo);
      if (detect_collisions) then
           ncv_report_collisions(nc, ginfo);
      set_machine_status(nc.status);
   end;
end;
```

Task scheduler for **ncv_sync_block**

```
task do_nc_tasks(nc: nc_machine; log: list of gcode_info);
var g: gcode_info;
begin
   for g in log do default_do_nc_tasks(nc, g);
end;

task do_nc_tasks(sb: ncv_sync_block);
var g: gcode_info;
begin
   sb.nc.status.current_state := 'running';
   do_nc_tasks(sb.nc, sb.gc_list);
   sb.nc.status.current_state := 'idle';
end;
```

Example 9.5

Suppose, for machine **vmc**, a subroutine is contained in a list of G code statements; we construct the **ncv_sync_block** as follows:

```
task vmc_mk_sync_block(nc: nc_machine; newv:
                       vtranscript; block_no: integer; los:
                       list of string): ncv_sync_block;
var   s: string;
      logc: list of gcode_info;
begin
   logc := emptylist(gcode_info);
   for s in los do
   begin
      gc_line := s;
      vmc_handle_stmt(nc);
      logc := cons(copy2(gcode_stmt as_type ob) as_type
                  gcode_info, logc);
   end;
   logc := reverse(logc);
   vmc_mk_sync_block := mk_ncv_sync_block(nc, newv,
                                          block_no, logc);
end;
```

Suppose the subroutine **P100** performs tool change using the following G code statements:

```
P100 == list('(Subroutine P100)',
'N001G00G91G28Z0.',
'N005G49',
'N005M06');
```

The sync block can be added to the list of subroutines by

```
subroutine_P100 == vmc_mk_sync_block(vmc,
                                     vmc_gwindow, 100, P100);
vmc_subroutines := cons(subroutine_P100,
                        vmc_subroutines);
```

continued on next page

Example 9.5 (continued)

The task **vmc_do_gtask** from Example 9.3 can be modified as follows:

```
task vmc_do_nc_tasks(nc: nc_machine; ginfo: gcode_info);
var i, g, m: integer;
begin
   update_gcode_window(ginfo);
   update_gcode_status("vmc_gcodes, ginfo.gcode, 1);
   if g.got_p then do_nc_tasks(get_sync_block(g.p,
                                          vmc_subroutines);
   for i := 0 to (length(ginfo.gcode)-1) do { Do G code }
   begin
      g := ginfo.gcode[i];
      if (g >= 0) then
         do_gtask(g, nc, ginfo);
   end;
   if (ginfo.got_m) then                  { Do M code }
      for m in ginfo.mcode do do_mtask(m, nc, ginfo);
   if (detect_collisions) then
      ncv_report_collisions(nc, ginfo);
   set_machine_status(nc.status);
end;
```

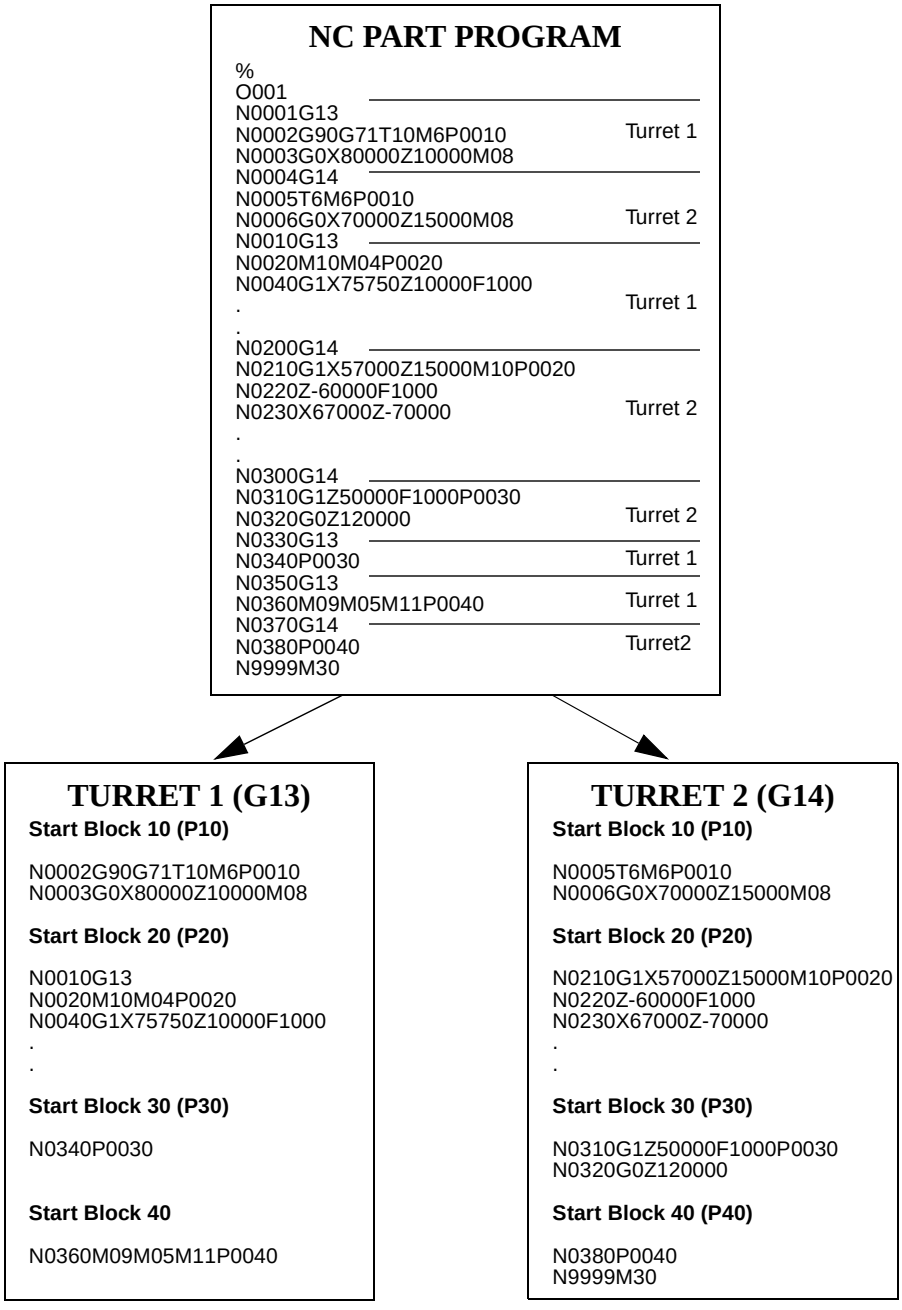


Figure 9-2 Synchronized cutting

Chapter 10

Using First Cut

Introduction to First Cut

First Cut, a numerical control verification software product, enables you to visually verify an NC program before releasing it to the shop floor. Using standard NC files, First Cut simulates the machining process. You see the material being removed from the stock as the cutter proceeds along the tool paths specified by the NC programming file.

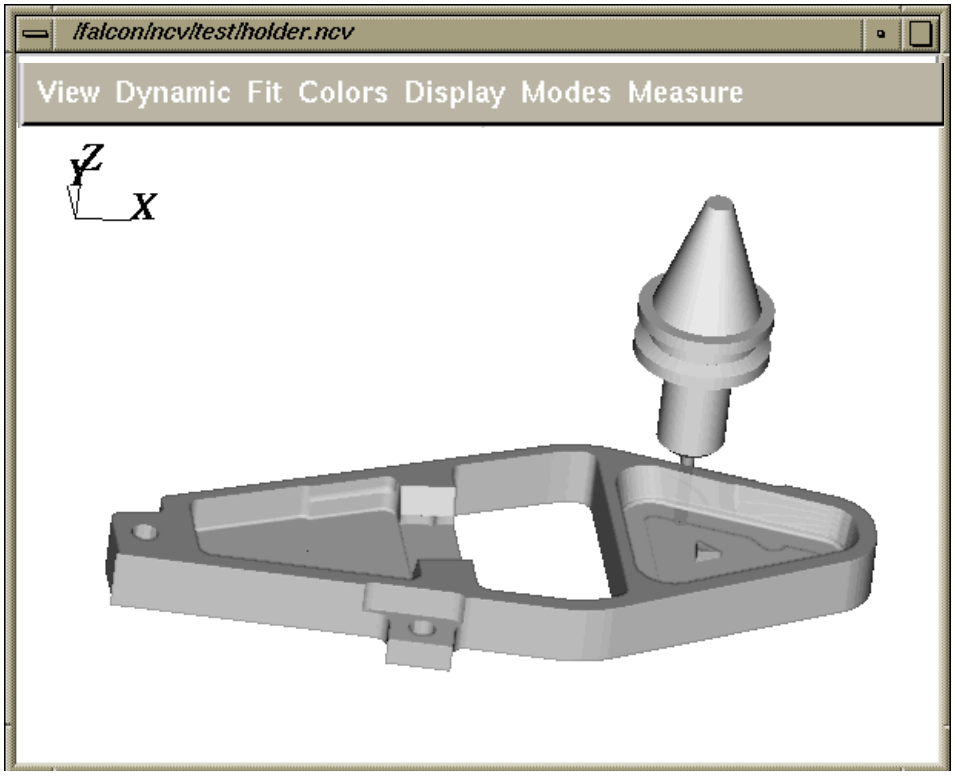


Figure 10-1 First Cut's *Geometry Window*

First Cut significantly reduces the need for the physical verification process and its related costs.

First Cut Product Features

The following are the main features of First Cut:

- ➢ Simulation of complex multi-axis cutter motion. Material removal is displayed in full color shaded images.
- ➢ Several types of errors are detected automatically: rapid cuts, cuts into fixtures, tool-holder collisions, and cutting above the flute length. Errors are displayed on screen and logged to a file, and screen images can be captured automatically at the point of error.
- ➢ Cutters are either APT 7-parameter cutters or free-form solids of revolution. Holders may be modeled as solids of revolution.
- ➢ Material removed by each cutter can be automatically displayed in a different color.
- ➢ During simulation, machining parameters (feedrate, spindle speed, coolant flow, rapid motion warning) are dynamically displayed.
- ➢ The cursor can be used to point to any location on the model to determine the precise coordinates, the surface normal vector, the material thickness, the motion responsible for the cut, and the cutter used to make the cut.
- ➢ Screen images can be saved at any time during simulation, and reviewed later as either a screen snapshot or a hard copy, whichever is more convenient.
- ➢ A series of simulations can be run as an unattended batch, and the individual simulations can then be replayed in fast mode, with features to step forward and backward through the simulation.

- ASCII or binary format SLA files can be read, and the geometry from the file can be created as part, fixture or stock. Stock and fixture models can also be created interactively.
- An as-designed part from an SLA file can be graphically compared to the machined part; the as-designed part is displayed translucently and overcuts and undercuts are highlighted.
- The total machining time, and the machining time to the current point, can be displayed continuously or at any time during the simulation.
- The current volume and volume removed can be displayed during or after the simulation.
- The images(s) of the machined part can be rotated a specific number of degrees about the horizontal or vertical axis at any time during or after simulation. Also, at any time the image can be rotated dynamically about the horizontal or vertical axis.
- Optionally, a portion of the tool path can be verified by either specifying a range of CL points or defining a box. Only the defined motions will be verified.
- Using the work-in-process (WIP) function, stock and fixture models can be saved at any point during a simulation.
- Models can be sectioned through any specified plane either by using the mouse to digitize the point at which the part is to be sectioned, or by entering the coordinates and the plane normal for the point.
- Machining of deep features can be observed by making the stock translucent or by sectioning the stock during simulation.
- The light source can be moved dynamically, and shadows can be rendered, to see details of the surface finish and for better realism.

➢ Input files (the files specifying cutter motions) are automatically run through conversion programs, which can be either provided customized or written by the end-user.

Product Overview

First Cut accepts input data from any CAM or APT system that has the ability to generate a standard IBM APT AC or 360 CL files, or G-codes. “NCV Input Data Formats” on page 10-76 contains details of acceptable input formats. The First Cut product supports conversion of binary CL files. Figure 10-2 illustrates this process.

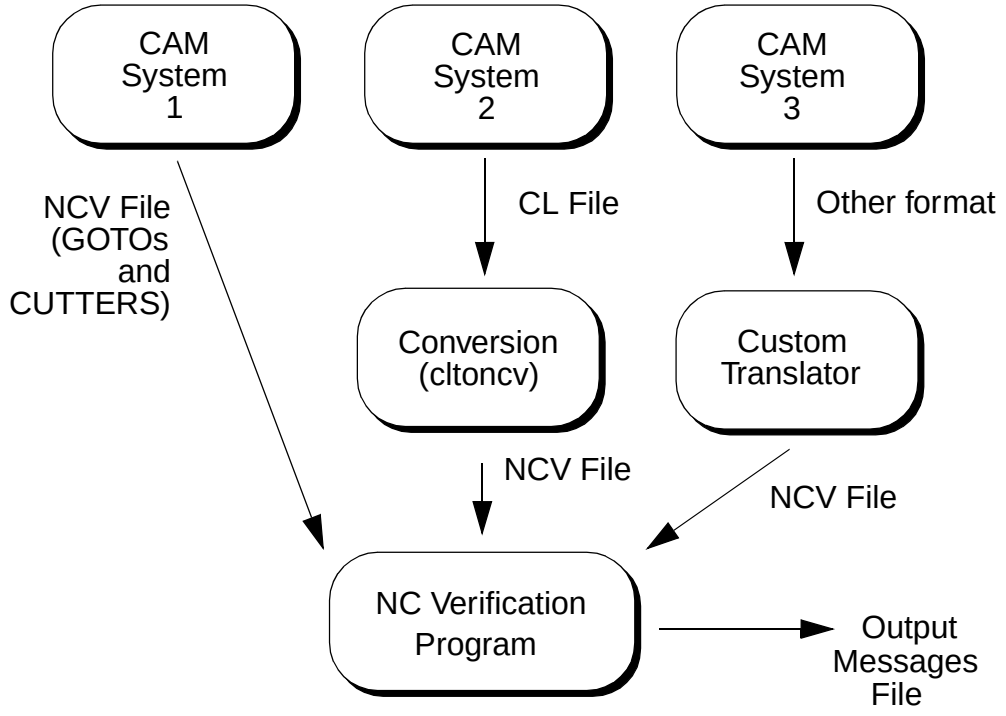


Figure 10-2 Binary CL file conversion

A control file may be used with the cltoncv program to define stock and fixture parameters and other defaults. See “The Control File Option” on page 10-69 for details. Stock and fixtures can also be imported using SLA format files, or can be defined within First Cut as boxes or cylinders, or defined using profiles sweeps.

For most CAM systems, the NCV CL file converter utility (cltoncv) combines the CL file and control file (if used), and converts the data into NCV simulation format. A customized translator may be required for file formats from other CAM systems; this can be written either by the end-user or by SILMA. The converted data is called the NCV file.

First Cut uses the NCV input file for the simulation session. Image files may be created to allow screen images to be reviewed later. Also, the simulation may be recorded for playback later; there are many viewing options for replaying the simulation.

An “as-designed” part in SLA file format may be also be read in to the NCV program, for use in a graphical comparison with the “as-machined” part; overcuts and undercuts are highlighted.

Operation and User Interface

First Cut is an interactive graphics system which can reduce the time and cost involved in generating error-free NC programs. The NCV simulation is designed to help identify and correct inefficient tool motions.

The product provides a visual image for the verification of numerical control machining operations. The simulation of tool motion and material removal provides a graphical representation of a work-in-process model. As the cutter follows the tool paths specified by the NC programmer, the user sees the part emerging from the stock. This process improves shop floor productivity by providing a cost effective alternative to “tape tryouts” on the machine tool.

First Cut Simulation Overview

First Cut simulates the machining process using the Center Line (CL) file generated by an NC processor such as Automatically Programmed Tool (APT). The CL file is converted to produce a data input file, called the NCV file, which is used by the **ncver** simulation program. This is illustrated below.

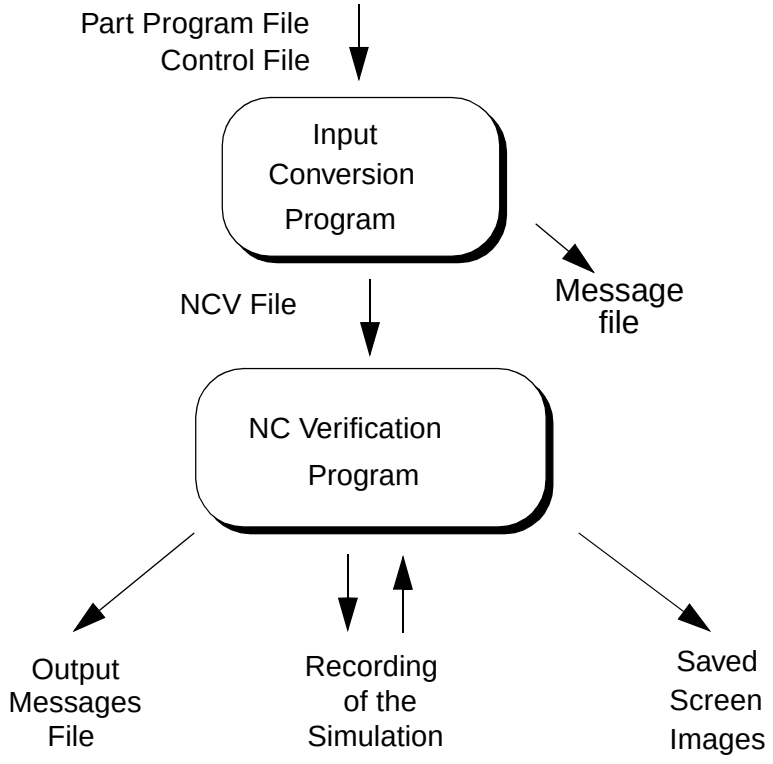


Figure 10-3 First Cut machining process

NOTE File conversion must be completed before you can begin a simulation session.

User Interface General Features

During a simulation, information about the cutter parameters, programmed feedrate and units, spindle speed and direction, and coolant flow is displayed. You can also, during simulation, determine which cutters made specific cuts by interactively selecting the display color of the affected stock material. Another color option will change the cut color automatically at each cutter change.

Processing can be interrupted, at any time, and the view modified to

- ➢ Inspect an apparent error
- ➢ Display the CL-ID and GOTO statement for a motion that cut a particular point on the part model
- ➢ Measure any particular point or stock or part thickness
- ➢ Save an enhanced image of the screen
- ➢ Change the simulation mode
- ➢ Read or write a work-in-process file
- ➢ Run a simulation on a subset of the input file
- ➢ Rotate the part vertically or horizontally, or zoom in on the view, for inspection of particular areas
- ➢ Section cut the model
- ➢ Start or stop recording the simulation
- ➢ See the machining time for the part, up to that point

First Cut has many features, such as pointing, image enhancement, flip, and zoom, that are used to evaluate the work-in-process model.

The simulation session can be run interactively, or one or more input files can run unattended. In either mode, you can record the session for later playback, and/or you can automatically store screen images at each cutter change or error, to review later. You can detect errors and identify inefficient tool motions either live during the simulation, or when replaying the recording, or when reviewing the images.

First Cut Functions

This section describes the First Cut functions grouped by the window in which they are accessed.

Introduction to the Windows Used for First Cut Functions

Switching on ❑ Metal Removal in the Simulation Setup panel displays the Metal Removal Setup panel and the *Metal Removal Window*. The other window that is used for metal removal is the *Geometry Window*, which is displayed by selecting *Create Geometry Window* from the **Windows** pulldown menu in the *Metal Removal Window*.

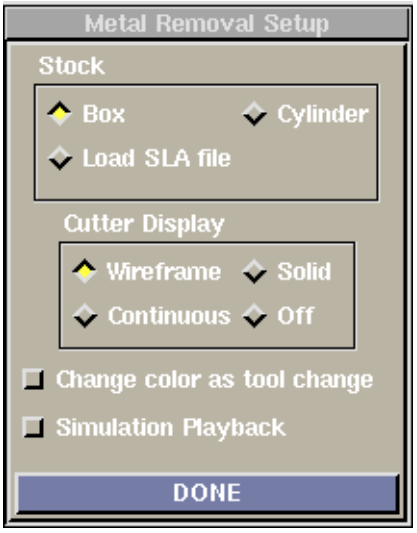


Figure 10-4 The Metal Removal Setup panel

The Metal Removal Setup panel is described in “Using the Metal Removal Setup Panel” on page 10-9.

Using the Metal Removal Setup Panel

The Metal Removal Setup panel is used to load the NC files you wish to verify, select the number and types and of views you want, and set the general controls you want applied. This panel is also used to carry out any stock and cutter definition work you require.

Defining the Stock

Toggling ◆ Load SLA file displays the Select SLA file panel.

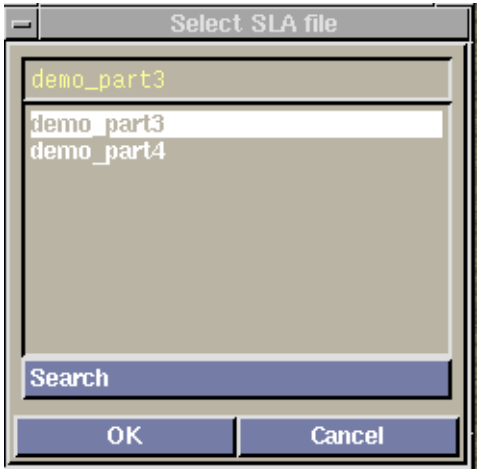


Figure 10-5 The Select SLA file panel

Setting the Cutter Display

◆ Wireframe mode is the default setting.

Simulate Mode

This switch takes you into Simulation (shaded) mode. Selecting this button causes the following:

- The wireframe stock and fixture models in each *Geometry Window* become shaded.
- The buttons that control the simulation (*Go*, *Stop*, etc.) become active.

When you switch on ❑ Simulation Playback, you are asked to enter a filename. The purpose of this is to prevent you from inadvertently losing the results of your simulation run.

Figure 10-6 Name requestor

Metal Removal Window

The *Metal Removal Window* provides all the basic set up functions, top-level controls for running the simulation, and message and reporting facilities.

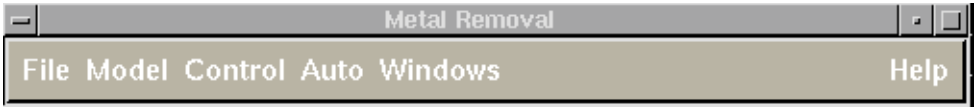


Figure 10-7 The *Metal Removal Window*

Table 9-2 describes the *Metal Removal Window* selections and tells you where the menu is described in greater detail.

Menu	Description
File	Provides the file reading and writing functions. See “File Menu” on page 10-15.
Model	Provides model manipulation capabilities, including stock and fixture definition. See “Model Menu” on page 10-22.
Control	Enables you to control how First Cut should operate in various ways. You can also define defaults for items such as cutters. See “Control Menu” on page 10-31.

Table 9-2 *Metal Removal Window* selections

Menu	Description
Auto	Enables you to specify various actions to be carried out automatically during the simulation. See "Auto Menu" on page 10-36.
Windows	Enables you to create additional views of the simulation. See "Windows Menu" on page 10-40.

Table 9-2 *Metal Removal Window* selections (continued)

Geometry Window

The *Geometry Window* displays the simulation. Selecting *Create Geometry Window* from the **Windows** pulldown menu in the *Metal Removal Window* displays the *Geometry Window*.

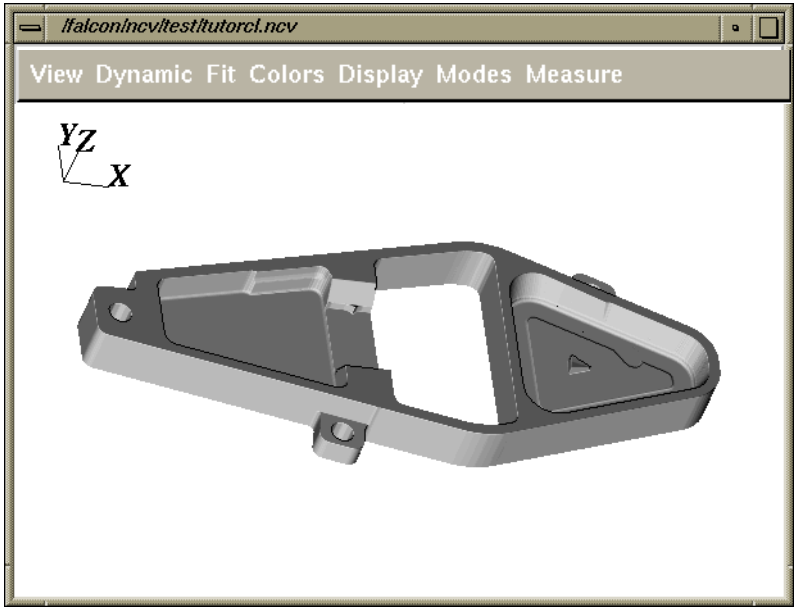


Figure 10-8 The *Geometry Window*

Table 9-3 describes the *Geometry Window* selections and tells you where the menu is described in greater detail.

Menu	Description
View	Enables you to set the view orientation in the window. Different windows can have different views. See “View Menu” on page 10-42.
Dynamic	Enables you to rotate, pan, and zoom the model while you are setting up your simulation. Also, during simulation, it allows you to dynamically rotate, zoom or change the light source. See “Dynamic Menu” on page 10-43.
Fit	Enables you to fit the model to the window and center the origin within the window. See “Fit Menu” on page 10-46.
Colors	Enables you to set the color of cuts. See “Colors Menu” on page 10-47.
Display	Enables you to switch on and off the display of the axes, the cutter, and shadows. See “Display Menu” on page 10-48.
Modes	Enables you to section the model, rotate it, and compare the as-manufactured model with the as-designed part. See “Modes Menu” on page 10-49.
Measure	Enables you to take various measurements on the part model, including machining time. Chip removal is also carried out here. See “Measure Menu” on page 10-55.

Table 9-3 *Geometry Window* selections

Information Display

First Cut dynamically updates the information display throughout the simulation. The display contains data regarding the items shown in the illustration:

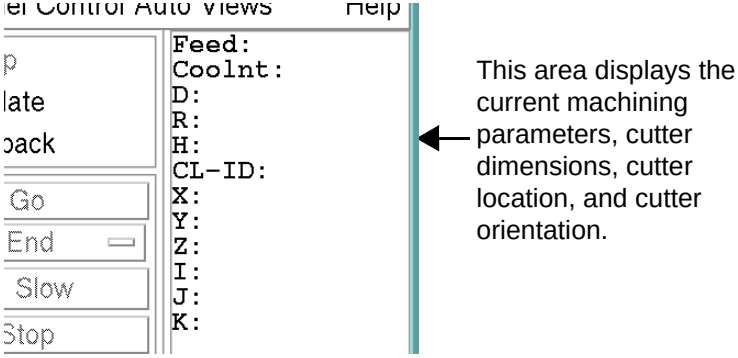


Figure 10-9 The information display fields

In more detail, the display fields are

Feed

This is the data from the RAPID and **FEDRAT** statements encountered during simulation. The feedrate value and units are displayed as IPR (inches per revolution), IPM (inches per minute), MMPM (millimeters per minute), or MMPR (millimeters per revolution). If no feedrate value was specified in the NC program file, the field is blank. During a RAPID motion, the field displays the word RAPID. After a RAPID, the field displays the feedrate that was most recently set prior to the RAPID.

When a feedrate is in effect, a white cutter is displayed in wireframe, and a beige cutter in solid.

If the motion is “rapid”, the cutter will turn red and the display will say RAPID; also, stock cuts will be flagged as errors. Three conditions can make a motion rapid:

- Use of the RAPID statement.

- A feedrate higher than the **MAX_FEED** parameter in the control file (this is only relevant to file being converted by the **cltoncv** program, which uses the control file).
- A feedrate higher than the maximum specified in the Max Feedrate dialog.

CoolInt

This field displays the data from each **COOLNT** statement encountered during simulation.

D

Displays the diameter of the current cutter.

R

Displays the corner radius of the current cutter.

H

Displays the height of the current cutter.

CL-ID

Displays the CL-ID of the current point.

X, Y, Z

Displays the location of the cutter.

I, J, K

Displays the axis vector of the cutter.

Metal Removal Window Functions

The *Metal Removal Window* provides all the basic set up functions, top-level controls for running the simulation, and message and reporting facilities.

Figure 10-10 The *Metal Removal Window*

File Menu

The **File** pulldown menu provides the file reading and writing functions. Selecting **File** from the *Metal Removal Window* displays the **File** menu.

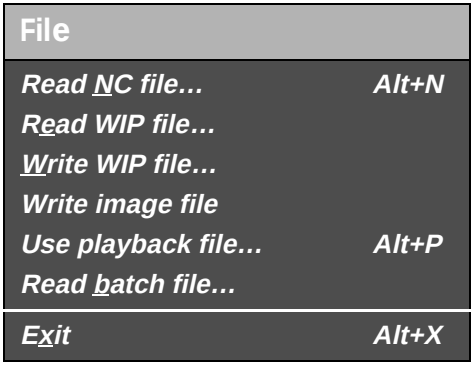


Figure 10-11 The **File** pulldown menu

The Read NC File Panel

The Read NC File panel provides the capabilities for browsing, filtering and selecting files for use in NCV. Selecting *Read NC file...* from the **File** pulldown menu displays the Read NC File panel.

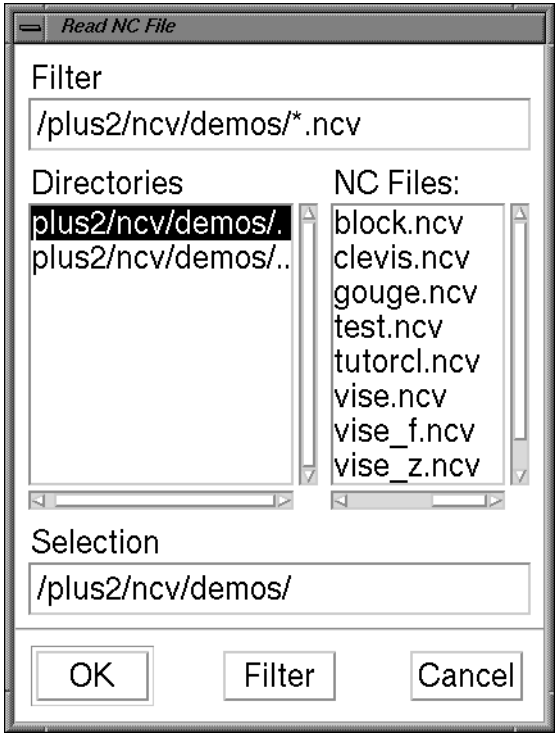


Figure 10-12 The Read NC File panel

To the center left of the window is the Directories box, which displays the list of current directories. The name of the directory in use is highlighted.

Above the Directories box is a Filter box. This works using any combination you wish of directory and filenames, and wildcards. A wildcard is an asterisk or question mark (* or ?); an asterisk matches any string; a question mark matches any single character; they are used to denote any set of characters when you are searching for a name. In the

example you can see that the filter has been set to the highlighted directory; you could have keyed this in, or selected it from the file list using the left mouse button.

The end of the filter has been set to *.ncv, which means that you want to see all files in the selected directory that have a suffix of **.ncv**.

In accordance with the Filter, the files listed in the NC Files box are all those with the given suffix.

Input Name Conventions and Pre-Processing

You can use any names and suffixes you wish for your files. First Cut defaults to the suffixes **.ncv** for NC program files, **.catia** for NC program files output by CATIA, **.gc** for G-code files, **.play** for playback files, **.wip** for work in process files, and **.stl** for stereolithography format files.

When you select the file that you wish to process, First Cut runs one of several pre-processor programs to convert the file to its standard input format.

You may, if you wish, produce your own script, and give it the name **ncvin** with a suffix of your own choosing, and then use the same suffix for your input files.

Detailed discussion and descriptions of input are in “Converting a CL File (cltoncv)” on page 10-66 and “NCV Input Data Formats” on page 10-76.

Output Name Conventions

ncver.out is the file that contains the message log maintained by First Cut during your entire simulation session. This file contains all messages, including error messages, that were reported during the session.

Other output files are named using the first 6 characters of the NC program file name, followed by a 3-digit serial number indicating the sequence of the message, followed by a suffix as follows:

`.wip`	work in process
`.xwd`	an image file
`.play`	a session recording file

Scroll Bars

Note the scroll bars to the right and below the lists of directories and NC files. If you put your cursor on the scroll bar, you can scroll up and down the lists, or from left to right of any name.

Changing the entry in the Filter box, and then clicking *Filter* at the bottom of the window, causes the list of files to be replaced by those matching the new filter.

If you select a file with a single click of the left mouse button, the name will appear in the Selection box, and you can then select *OK* to read in the file. Alternatively, a quick double click on the file name also causes it to be read in.

As the file is read in, the Read NC File dialog is dismissed, and First Cut creates a *Geometry Window* with a wireframe model of the stock and tool path.

When you read in a new NC file, the following occurs:

- All control values and default cutter parameters are re-set to their defaults.
- In Setup mode, any existing stock and fixtures are deleted.
- In Simulation mode, First Cut assumes you want to run the new NC program file against the existing work in process, and ignores any geometry in the new file.
- If the input file can’t be read or contains errors, a message is displayed in the message window.

The *Read WIP file...* Selection

This option is only available in Simulation mode. Selecting *Read WIP file...* from the **File** pulldown menu enables you to select a file.

Select the file you want and read it in as described above in "The Read NC File Panel" on page 10-16.

This causes First Cut to delete any existing *Geometry Window*s and create new ones matching those when the file was written. First Cut displays the solid WIP model in them.

After the file has been read, you can run the normal simulation functions. For example:

Step 1: Begin the simulation at the beginning of the NCV input file.

Step 2: Specify a subset range of cutter location IDs. This is useful if you want to resume the simulation at a particular CL point.

4. Select a subset box of cutter motions.

5. Retrieve new cutter motions by reading in a new NCV input file.

The *Write WIP file...* Selection

The Write WIP file panel is used to create a work-in-process file. Selecting *Write WIP file...* from the **File** pulldown menu displays the Write WIP file panel.

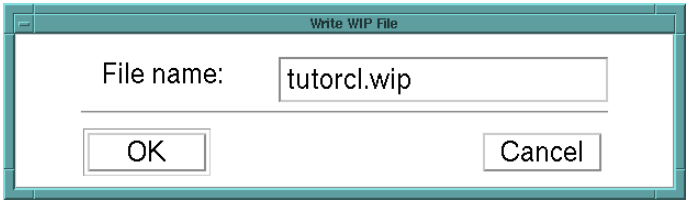


Figure 10-13 The Write WIP file panel

Enter the desired file name and select *OK*.

If the file already exists, you will be asked whether to over-write it.

The work-in-process file contains the following information:

- Number of *Geometry Window*s
- Size, shape, and orientation of the stock and fixture in each *Geometry Window*
- Solid work-in-process model in each *Geometry Window*

The work-in-process file does not contain the following information:

- Any dynamic graphics display information, such as zoom, rotation or section states
- NC program

You can write multiple work-in-process files during a single simulation session.

NOTE An average file size is 5 megabytes.

The *Write image file* Selection

The *Write image file* selection in the **File** menu is used to create a "snapshot" of the current screen image.

You can create an image file using this button at any time in a simulation session. Image files can also be generated using **Auto** options described in the section on "Auto Menu" on page 10-36.

The image files are X Window **.xwd** files and may be viewed and printed using standard X-Windows utilities. A description of how to use the utility is provided in "Viewing Saved Images" on page 10-167.

You can also create **.xwd** files with black images on a white background.

The *Use playback file…* Selection

Selecting the *Use playback file…* button from the **File** menu displays the Use Playback File panel, which is used to select and read the specified playback file. These features are fully described under “The Read NC File Panel” on page 10-16.

Use playback file… is used in Set up, Simulation, and Playback modes. In Simulation and Setup modes you can key in the name of the playback file to be created when you click *Record*, which will be used also as the name of the file to be read when you hit Playback. In Playback mode, it reads the specified playback file.

The *Read batch file…* Selection

The batch file facility requires the name of a file that contains a list of file names to be processed sequentially and automatically once you have commenced your simulation. Note that if you are processing a series of files automatically using this feature, then all the defaults that you set before commencing your first simulation will apply throughout the series.

The *Exit* Selection

This selection is used to exit First Cut without quitting Soft Machines. You are asked to confirm that you really want to leave First Cut.

Figure 10-14 Exit confirmation requestor

OK exits and remove all the First Cut windows. *Cancel* will return you to First Cut.

Model Menu

The **Model** pulldown menu provides model manipulation capabilities, including stock and fixture definition. Stock and fixtures can be created using the **Model** menu. They may be created from a box, a cylinder, or a profile sweep, or read in from an SLA file. The procedures for creating stock and fixtures are identical, only differing by the Type displayed in the dialog box.

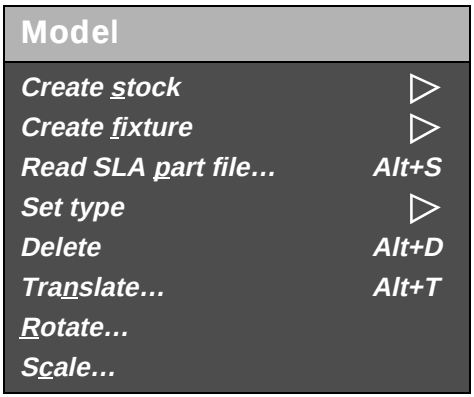


Figure 10-15 The **Model** pulldown menu

Stock is displayed in wireframe mode in light blue; fixtures are drawn in white.

The options on the **Model** menu are explained in the following sections.

The *Create stock* selections

The *Create stock* selections are used to select the type of stock geometry.

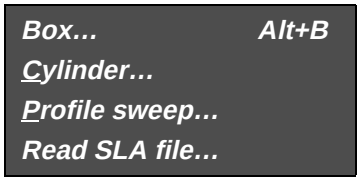


Figure 10-16 The *Create stock* selections

Creating a Box

The Create Box panel is used to create a stock or fixture box orthogonal to the coordinate axes using two corner points. Selecting *Box...* from the *Create stock* or *Create fixture* selections displays the Create Box panel.

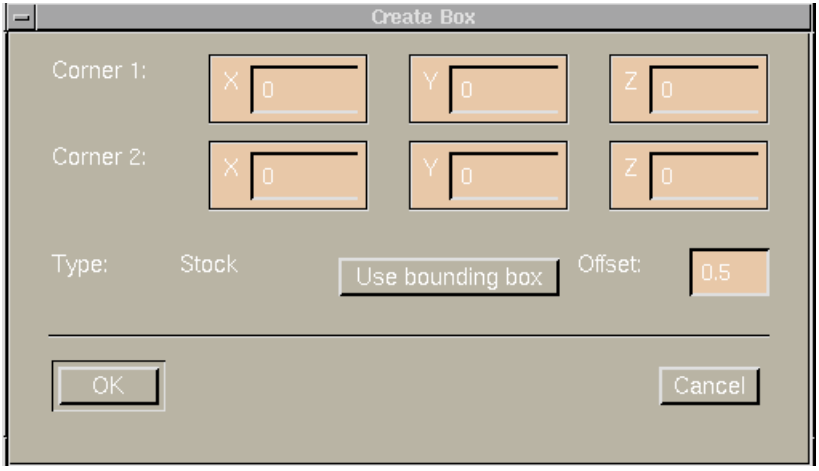


Figure 10-17 The Create Box panel

You can either enter the coordinates of the corners of the box in the fields or click *Use bounding box* to establish the coordinates.

Use bounding box creates the smallest box that completely encloses the tool paths. The size of the box may be modified by entering a value for Offset.

Offset increases the size of the bounding box in all directions by the value entered; that is, it offsets each face, so an offset of 0.5 increases each dimension by 1.0.

Click *OK* to create the box or *Cancel* to dismiss the panel.

Creating a Cylinder

The Create Cylinder panel is used to create a stock or fixture cylinder. Selecting *Cylinder...* from the *Create stock* or *Create fixture* selections displays the Create Cylinder panel.

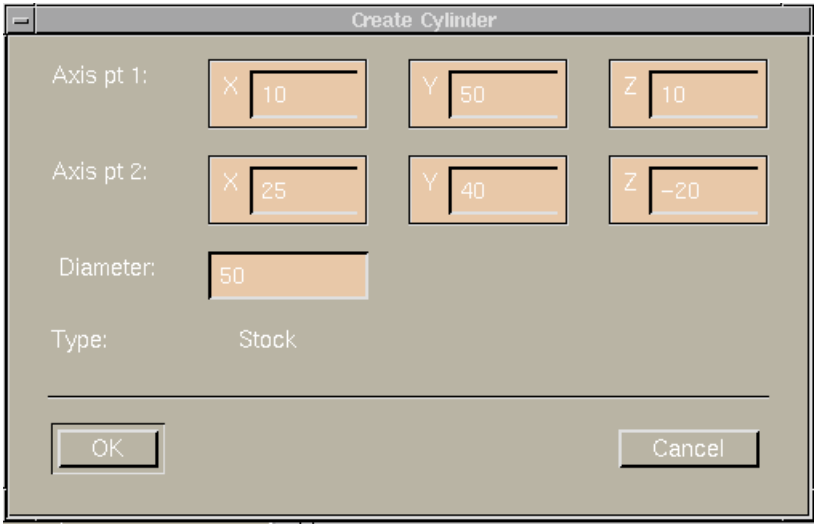


Figure 10-18 The Create Cylinder panel

The cylinder axis is determined by the endpoints. To define a cylinder:

Step 1: Enter the X, Y, Z coordinates of the two endpoints.

Step 2: Enter the cylinder diameter in the Diameter field.

Step 3: Click *OK*.

Creating a Profile Sweep

Selecting *Profile sweep...* from the *Create stock* or *Create fixture* selections displays the Create Profile Sweep panel.

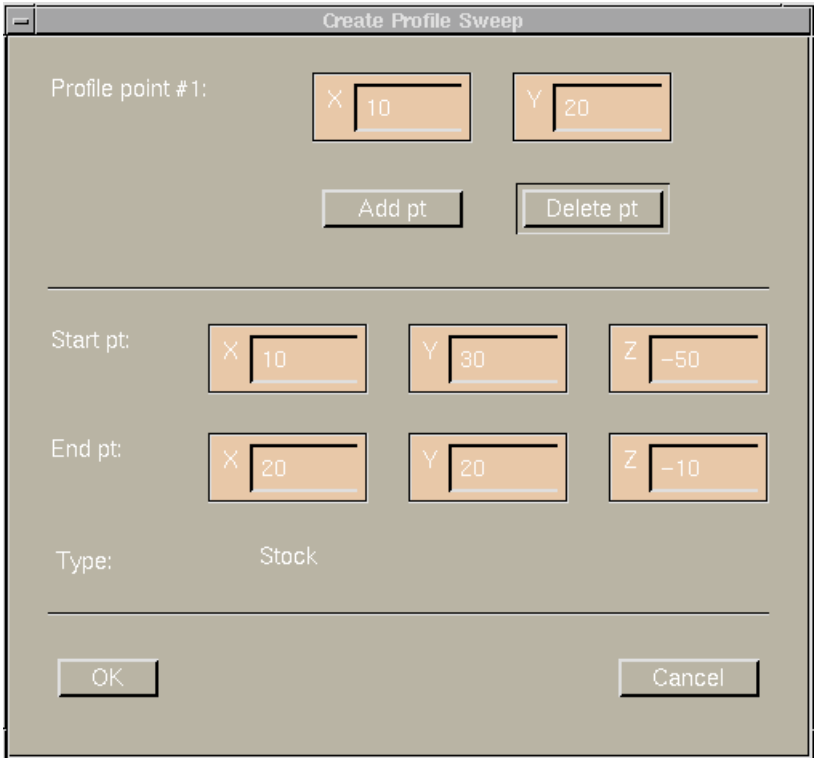


Figure 10-19 The Create Profile Sweep panel

To define a profile sweep:

Step 1: Enter a set of X, Y coordinates for the first point.

Step 2: Select *Add pt.*

The first coordinate values display in the message area as the Profile Point counter is incremented from 1 to 2.

Step 3: Enter a second set of X, Y coordinates for the second point.

Step 4: Select *Add pt.*

These values appear in the message window and the profile point counter is incremented. A green line appears in the *Geometry Window*s connecting the two points.

Step 5: Repeat the last step to enter successive sets of coordinates.

As you continue to enter points, First Cut continues to draw a line from the previous profile point to the current point.

Step 6: Enter the start point's coordinates.

Step 7: Enter the end point's coordinates.

Step 8: Select *OK*.

The profile sweep automatically closes the first point and the last point entered. The profile sweep appears in the selected color (stock color is light blue, fixture color is white).

The values entered for Start Point and End Point determine the depth of the sweep and the vector which defines the sweep orientation.

While you are defining the sweep you can also modify it by selecting *Delete pt. Delete pt* enables you to continue to delete points until you have defined the correct shape.

The *Read SLA file…* Selection

The Read SLA File panel is used to select an SLA part model that is to be read in for the "as-designed" part to be compared with the "as-machined" part produced by the simulation. The imported part is drawn in dark blue. Selecting *Read SLA file…* from the *Create stock* or *Create fixture* menus displays the Read SLA File panel.

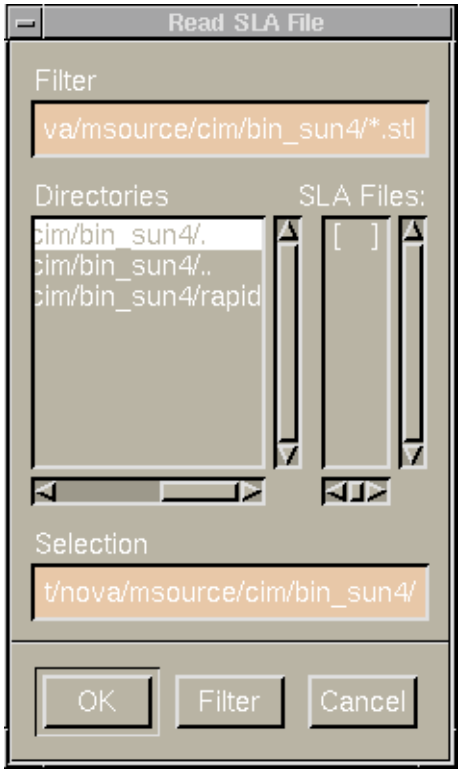


Figure 10-20 The Read SLA File panel

See "The Read NC File Panel" on page 10-16 for details of how to use the Read SLA File panel.

Creating a Fixture

Fixtures are created in exactly the same way as stock. The *Create fixture* selections are the same as stock, apart from displaying the type as fixture. See "The Create stock selections" on page 10-23.

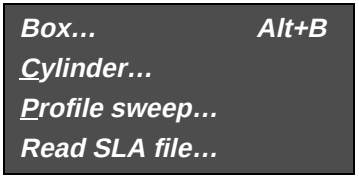


Figure 10-21 The *Create fixture* selections

Changing the Type of a Model

If a model has been incorrectly identified (e.g., as stock when it should have been a fixture), the *Set type* selections can be used to change the model's type. Select the model by clicking on it with the left mouse button. Select the desired type from the *Set type* selections.

Figure 10-22 The *Set type* selections

Deleting an Object

Select the item to be deleted by clicking in the view with the cursor, then selecting *Delete* from the **Model** menu.

The *Translate...* Selection

The Translate panel is used to move the part, stock, fixtures or tool path. Selecting *Translate...* from the **Model** pulldown menu displays the Translate panel.

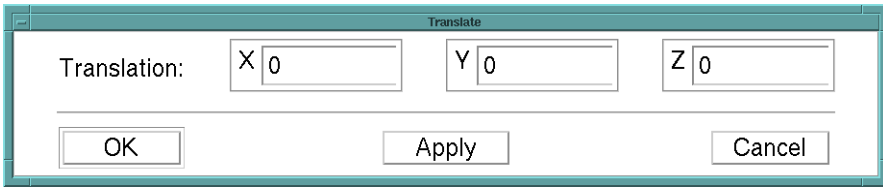


Figure 10-23 The Translate panel

To effect the translation, type in the X, Y and Z components of the required offset vector then select either *Apply* or *OK*.

Selecting *Apply* applies the translation and leaves the panel displayed. If new values are entered and *Apply* is selected again, the new values will be applied instead of the first set of values, not in addition to the first set.

Selecting *OK* will effect the translation permanently and dismiss the panel.

Selecting *Cancel* dismisses the panel and all remains as it was before *Translate...* was selected.

The *Rotate...* Selection

Selecting *Rotate...* from the **Model** pulldown menu displays the Rotate panel.

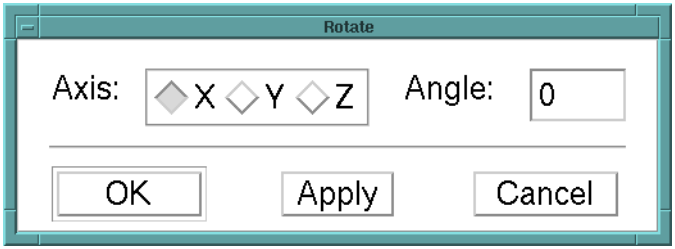


Figure 10-24 The Rotate panel

To rotate an object:

1. In the *Geometry Window*, select the solid or tool path that you wish to rotate.
2. Select *Rotate...* from the **Model** menu. The Rotate panel is displayed.
3. In the Rotate panel, select the axis about which the part is to be rotated and enter the number of degrees rotation in the Angle box.

   As with the Translate panel, *Apply* applies the absolute value and does not add it to any previous value used. *OK* effects the rotation permanently and dismisses the panel.

   Selecting *Cancel* dismisses the panel and all remains as it was before *Rotate...* was selected.

Scaling a Model

The Scale panel is used to change the size of a part, stock or fixture model. Before displaying the panel, select the model to be scaled, using your left mouse button. Selecting *Scale...* from the **Model** menu displays the Scale panel.

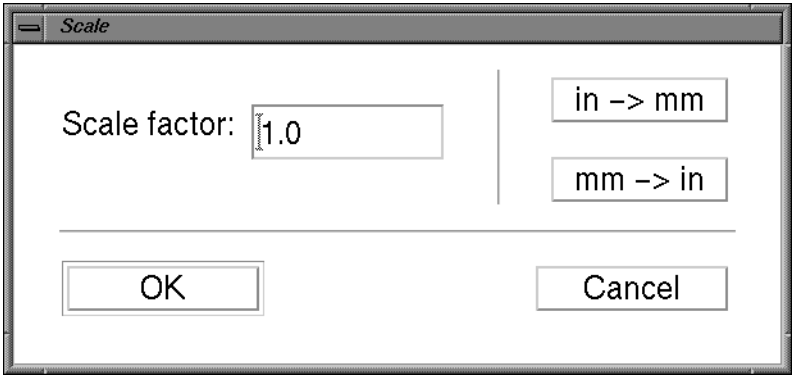


Figure 10-25 The Scale panel

Typically, this panel is used to convert between English and metric sizes. To do this, simply click on the *in->mm* or *mm->in* button. The Scale factor will be updated with the appropriate value. Select *OK* to update the model.

Alternatively, you can enter a value in the Scale factor field and select *OK*.

Scale factors smaller than 10^{-4} or larger than 10^{4} are not allowed. However, scaling by larger factors can be accomplished by repeated scale operations if necessary.

Control Menu

The **Control** pulldown menu enables you to control how First Cut should operate in various ways. For example, if only a portion of the input file is to be simulated, then this can be defined by delimiting the range of the tool-path motions to be executed. Defaults for items (such as cutters) are also defined here.

Figure 10-26 The **Control** menu

Defining the Default Cutter

The Default Cutter panel is used if the NC program file contains **GOTO**s before the first cutter definition. The panel selections are used to define the dimensions of the cutter that will be used for those **GOTO**s. Selecting *Default cutter...* from the **Control** pulldown menu displays the Default Cutter panel.

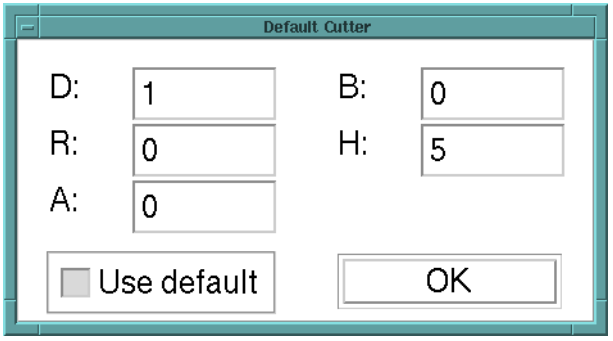


Figure 10-27 The Default Cutter panel

The fields specify the cutter dimensions. The default cutter is defined by the values D, R, E, F, ALPHA, BETA, H, conforming to the APT seven-parameter cutter definition convention.

❏ Use default turns the default cutter on or off. Switching on displays the CL points that precede the first cutter definition and cuts them using the specified cutter. Switching off removes the CL points and they will not be cut.

Defining the Default Tool Axis

The Default Tool Axis panel is used to define the tool axis that will be used during simulation whenever the axis is not explicitly specified in the NCV input file (for instance, in a

three-axis file or after a **MULTAX OFF** statement in a multi-axis file). Selecting *Default axis...* from the **Control** pulldown menu displays the Default Tool Axis panel.

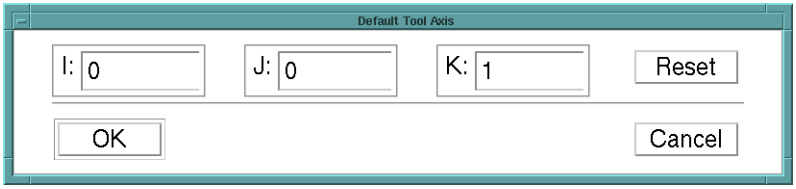


Figure 10-28 The Default Tool Axis panel

To define the default tool axis, enter the X, Y and Z axis vector components. The vector does not have to be normalized.

Reset resets the fields to First Cut's original default axis.

Cancel dismisses the panel without changing the default axis.

The *Cutter limits...* Selection

The Cutter Limits panel is used to specify limits to override the programmed minimum and maximum length and minimum diameter. Selecting *Cutter limits...* from the **Control** pulldown menu displays the Cutter Limits panel.

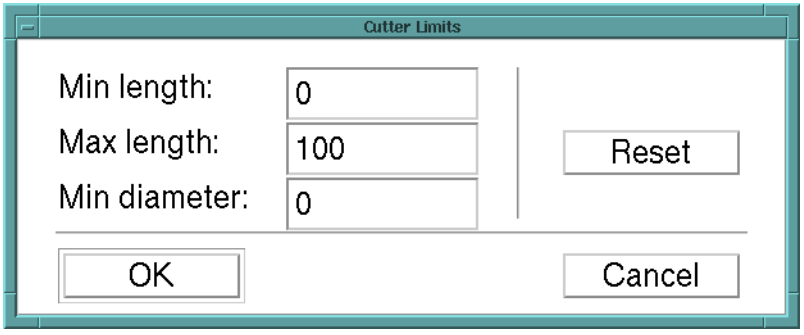


Figure 10-29 The Cutter Limits panel

The minimum and maximum length and minimum diameter fields specify limits to override the programmed length and/or diameter. The cutter length and/or diameter test is applied to all **CUTTER** and **PPRINT TRUE C** statements in the NC program file.

NOTE	In wireframe mode, the tool axis drawn at each CL point is the length of the cutter. So, if the minimum or maximum length is changed, and it actually affects any of the cutters, the axis lines for those CL points will change.

OK makes the specified changes and dismisses the panel.

Reset restores First Cut's original values (those you see when the panel is first displayed).

Cancel dismisses the panel without changing any values, even if *Reset* was selected.

Setting the Maximum Cutting Feedrate

The Maximum Feedrate panel is used to specify the maximum cutting feedrate. Faster feedrates are considered RAPIDs. Selecting *Max feedrate...* from the **Control** pulldown menu displays the Maximum Feedrate panel.

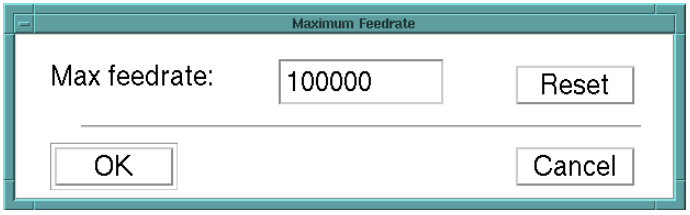


Figure 10-30 The Maximum Feedrate panel

OK makes the specified changes and dismisses the panel.

Reset restores First Cut's original values (those you see when the panel is first displayed).

Cancel dismisses the panel without changing any values, even if *Reset* was selected.

The *Subset range…* Selection

The Subset Range panel is used to specify that only a subset of the CL-IDs should be simulated. First Cut will then simulate the cutter motions for those CL points only. Selecting *Subset range…* from the **Control** pulldown menu displays the Subset Range panel.

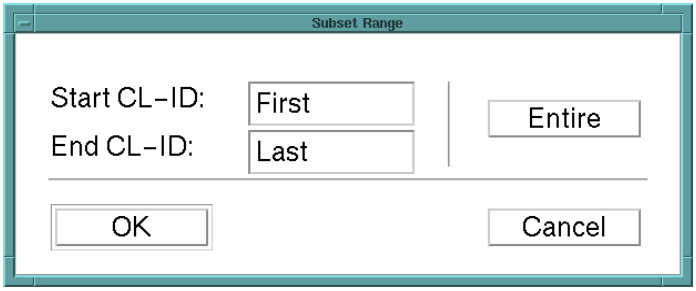


Figure 10-31 The Subset Range panel

The number of CL points selected for simulation is shown in the message area. *Entire* selects the entire NC program.

The Subset box… Selection

Subset box… is used to run the simulation on a specified set of motions by using the cursor to draw a box around the desired motions.

When you select *Subset box…*, a message is displayed in the message area instructing you to drag the mouse diagonally across the desired box. To select a subset box of tool paths:

1. Position the cursor at one corner of the box.
2. Press and hold the left mouse button while moving the cursor to the opposite corner of the box.
3. Release the left mouse button. The motions which lie inside or cross the box are selected for simulation.

If you are in Setup mode, you will see the selected motions highlighted. However, if you are using simulation mode, you cannot see the selected subset since the tool path is not displayed.

The Use entire NC program Selection

This makes all CL points active again, regardless of whether *Subset range...* or *Subset box...* was used.

The Multi-axis Switch

This selection is switched on automatically when an NC program file is read to reflect the presence or absence of multi-axis motions in the file. If you have a multi-axis file, switching it off will cause First Cut to skip the file's multi-axis motions.

Auto Menu

The **Auto** pulldown menu enables you to specify various actions to be carried out automatically during the simulation, for example, if the cut color should be changed automatically for each new tool.

Auto enables you to define functions that you wish to be executed automatically during a simulation. The **Auto** menu is invoked from the *Metal Removal Window*, and looks like this:

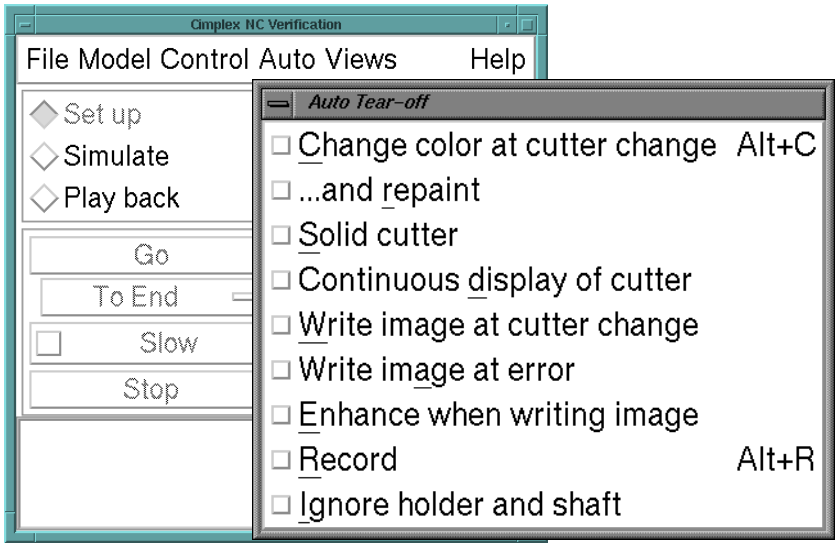


Figure 10-32 The **Auto** menu

The Change color at cutter change Switch

Selecting ❑ Change color at cutter change changes the color of the cuts each time a cutter change is encountered in the NCV input file.

The color cycle order is the order shown in the **Color** menu in the *Geometry Window* (see "Colors Menu," on page - 47). Once all colors are used, the cycle begins again.

The …and repaint Switch

Selecting ❑ …and repaint automatically selects ❑ Change color at cutter change.

Selecting this button repaints all cuts in the last color (yellow-green) before restarting the cycle. Using this button can aid you in inspecting the image by allowing you to see the work carried out by up to the ten most recent cutters.

The Solid cutter Switch

Switching this on causes the cutter to be displayed as a solid. Note that you can use this button during the simulation if you wish to switch between shaded and wireframe cutter display. See also “The Show cutter Switch,” on page - 48, which shows how to turn the cutter display on and off.

The simulation runs slightly slower if this is switched on. The switch has no effect in Playback mode.

The Continuous display of cutter Switch

Switching this on causes the cutter to be displayed continuously as it moves between CL-points. This mode is significantly slower than the default mode, which is to display the cutter once at each CL point. This switch has no effect in Playback mode.

The Write image at cutter change Switch

When you switch this on, image files of the current screen image are automatically generated at each cutter change, and also at the end of the NCV input file. “Output Name Conventions” on page 10-17 explains how the files are named, and “Viewing Saved Images” on page 3-36 explains how you may display the images on the screen or print them.

The Write image at error Switch

When you switch this on, image files are automatically generated whenever an error is detected, and also at the end of the NCV input file. Errors are defined as

- Any rapid cut into the stock
- Any cut into a fixture
- Any holder or shaft cut into stock or fixture

"Output Name Conventions" on page 10-17 explains how the files are named, and "Viewing Saved Images" on page 10-167 explains how you may display the images on the screen or print them.

The Enhance when writing image Switch

When you switch this on, the images in all *Geometry Window*s are automatically enhanced before the image file is written. Using this option, any previously unenhanced *Geometry Window*s will revert to their previous state, after the image is saved. For example, a view that was unenhanced before ❑ Enhance when writing image was selected, will be unenhanced when you resume the simulation. See "The Enhance Switch," on page - 49 for information on the enhance feature.

Similarly, if you select *Write image file* from the **File** menu when the auto-enhance mode is active, all *Geometry Window*s will be enhanced before the image file is written, but will afterwards return to their previous (enhanced or unenhanced) state.

The Record Switch

This option is only available in Simulation mode (see "Simulate Mode," on page - 9). It records the session for later playback using the playback option (see "Playback Mode," on page - 12).

The Ignore holder and shaft Switch

If you have specified a tool holder in your NC program, switching this on will cause the holder and shaft display to be turned off. Also, there will be no collision checking for the holder, and there will be no collision checking for the tool shaft, i.e., above the flute length.

Windows Menu

The **Windows** pulldown menu enables you to create additional views of the simulation.

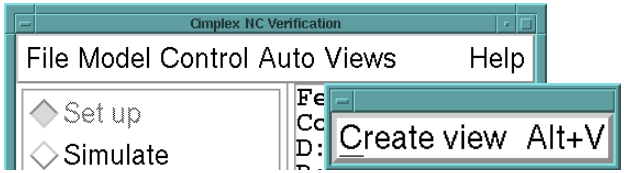


Figure 10-33 The **Views** menu

The **Views** menu, accessed from the *Metal Removal Window*, has one item, *Create View*, which allows you to create a new *Geometry Window* to view the simulation.

You may create as many views as you wish, and they may overlap.

You define the view you want in each window using the **View** and **Dynamic** menus in the *Geometry Window*, as described in “View Menu,” on page - 42, and “Dynamic Menu” on page 10-43.

NOTE	You can create new *Geometry Window*s only in Set up mode.

Help Menu

On-line assistance is provided by the NCV **Help** button, accessed from the *Metal Removal Window*.

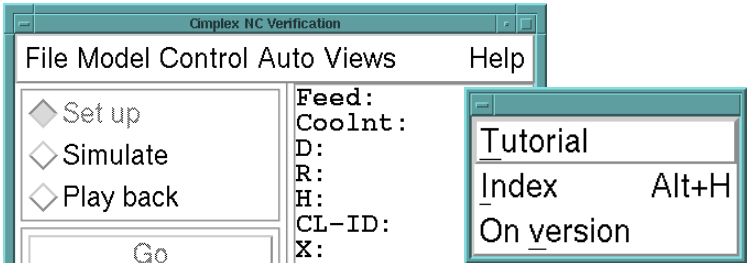


Figure 10-34 The **Help** menu

The **Help** facilities are

Tutorial	Displays the on-line tutorial.
Index	Displays an index of the **Help** topics, from which you can select the subject you wish to read.
On Version	Displays the version number of NCV.

Geometry Window Functions

When you read an NC file, a *Geometry Window* is created automatically, and the stock, fixtures and tool path are displayed in wireframe.

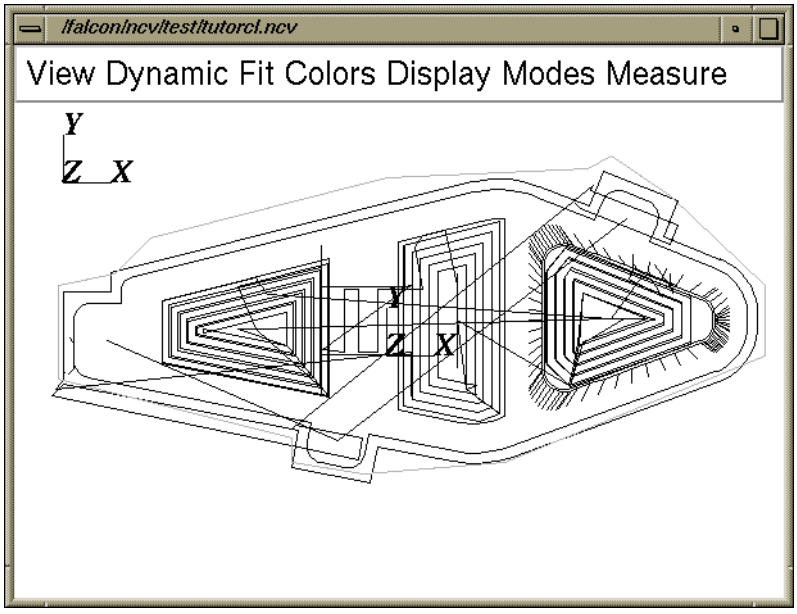


Figure 10-35 A *Geometry Window*

You can create more *Geometry Window*s using the **Views** menu in the *Metal Removal Window* (see "Windows Menu," on page - 40).

When you enter Simulation mode from the *Metal Removal Window*, the wireframe model is shaded in all your *Geometry Window*s.

At the top of the *Geometry Window* are pulldown menus to control the views of the part and evaluate the simulation. These are described below.

View Menu

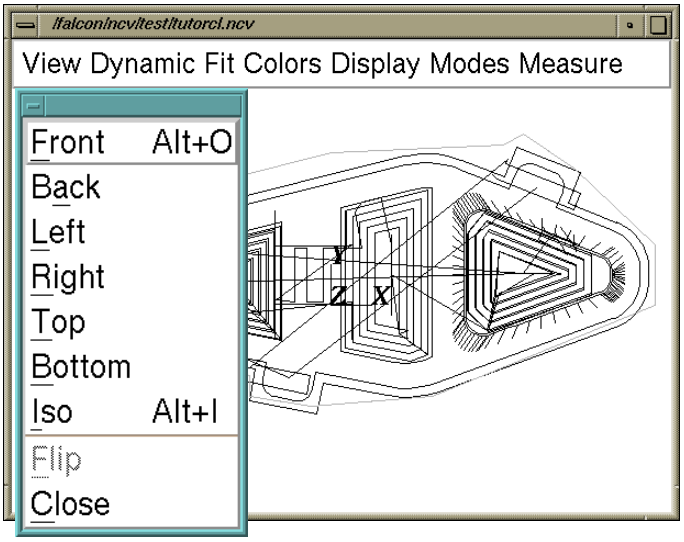


Figure 10-36 The **View** menu

The view descriptions are based around the coordinate system: the view shown in the illustration is the front, where you are looking down the positive Z axis; if you selected *Bottom*, then you would be looking at the other side from the negative Z axis. Similarly, a *Right* view would be from the positive X axis, and so on.

The *Flip* button is available only in Simulation mode; this enables you to rotate the part through 180 degrees around whatever is your current vertical axis, e.g., from a front view the image will be flipped over to a back view. Selecting *Flip* again returns the part to the original view.

If you select *Close* while in Simulation mode, you will be asked to confirm that you wish to remove the window, and, if so, then it will be dismissed.

Dynamic Menu

Selecting **Dynamic** from your *Geometry Window* displays this menu of the dynamic viewing modes.

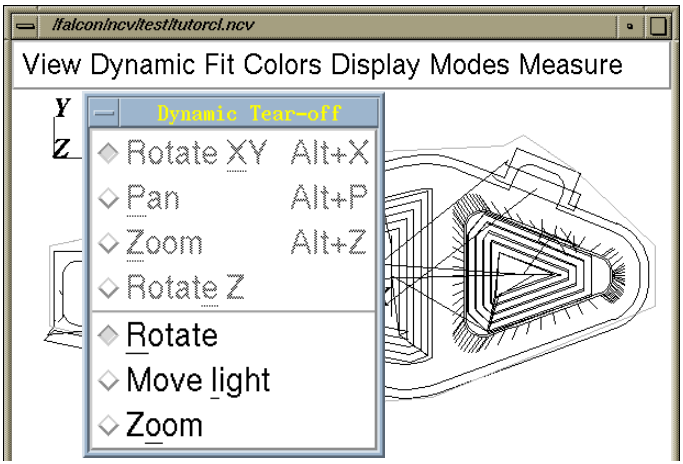


Figure 10-37 The **Dynamic** menu

The first four functions are activated when you are in Setup mode—they allow you to position and size the part for the simulation. The other three functions are activated when you are in Simulation mode—they control the dynamic functions of rotation, zooming and positioning of the light source.

All the viewing modes are controlled by cursor location when the middle mouse button is pressed. Dynamic viewing in the window continues until the mouse button is released.

Note that when you are in Simulation mode, you can also access the **Modes** menu, to get at a rotation function, described under “The Rotate… Selection,” on page - 51. Dynamic Rotation and Zooming can be carried out as described under “Mouse buttons” on page 2-7.

Setup Mode Selections

The Rotate XY Selection

Rotates the view around the origin. When the cursor is dragged to the right across the window, the Y axis rotates in the positive (counter-clockwise) direction. When the cursor is dragged to the left across the window, the Y axis rotates in the negative direction.

Another way to visualize it is that the front of the model follows the mouse.

The Pan Selection

Drags the model around the window, following the mouse.

The Zoom Selection

Scales the view up or down based on how the cursor is dragged across the window.

To enlarge the image, press and hold the middle mouse button while moving the cursor up the window. To shrink the image, press and hold the middle mouse button while moving the cursor down the window.

The Rotate Z Selection

Rotates the view around the line of sight. When the cursor is dragged up the window, the model rotates counter-clockwise. The rotation is reversed when the cursor is dragged down the window.

Simulation Mode Selections

The Rotate Selection

In Simulation mode, you can dynamically rotate the part model. To do this, toggle ◆ Rotate from the **Dynamic** menu:

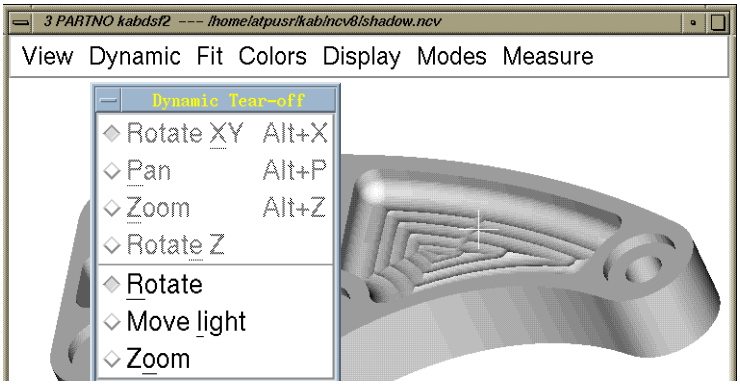


Figure 10-38 The **Dynamic** menu

Place your cursor to the left or right of center in your view of the part, and then drag it left or right to rotate about the vertical axis. To rotate about the horizontal axis, do the same thing above or below the center of your view of the part and drag the cursor up or down.

The Move light Selection

In Simulation mode, you can move dynamically the light source in a window.

Toggle ◆ Move light in the **Dynamic** menu, then either click the middle mouse button or drag it to place the light source. Clicking (or letting up) the button in the center of the window places the light source at the eyepoint, where it is normally. Clicking or letting up at the edges of the viewport places the light source in that direction, at right angles to the line of sight. Clicking or letting up in intermediate locations places the light source at intermediate directions.

The Zoom Selection

In Simulation mode, you can zoom up the image dynamically by toggling ◆ Zoom, as an alternative to using the Zoom Window feature.

As explained in "Mouse Buttons in Simulation Mode" on page 2-8, the Zoom Window feature enables you to select an area of the view, using the right-hand mouse button; this area is then re-drawn magnified to the window size.

However, Dynamic Zoom works by toggling ◆ Zoom from the **Dynamic** menu, and then selecting the point to be zoomed in your view; you then press the middle mouse button, and drag the mouse upward until you get the desired degree of magnification.

Fit Menu

Selecting **Fit** from your *Geometry Window* displays this menu:

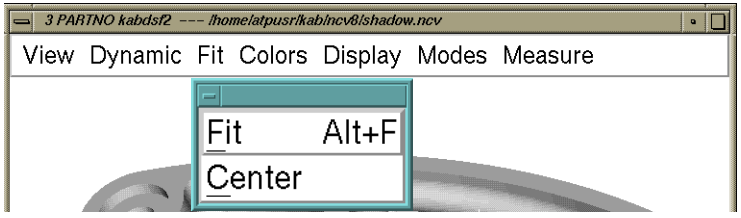


Figure 10-39 The **Fit** menu

Fit

Selecting *Fit* resizes the model to take up the full window.

Center

Selecting *Center* moves the origin of the model to the center of the window without changing its size.

Colors Menu

Selecting **Colors** from the *Geometry Window* displays this menu:

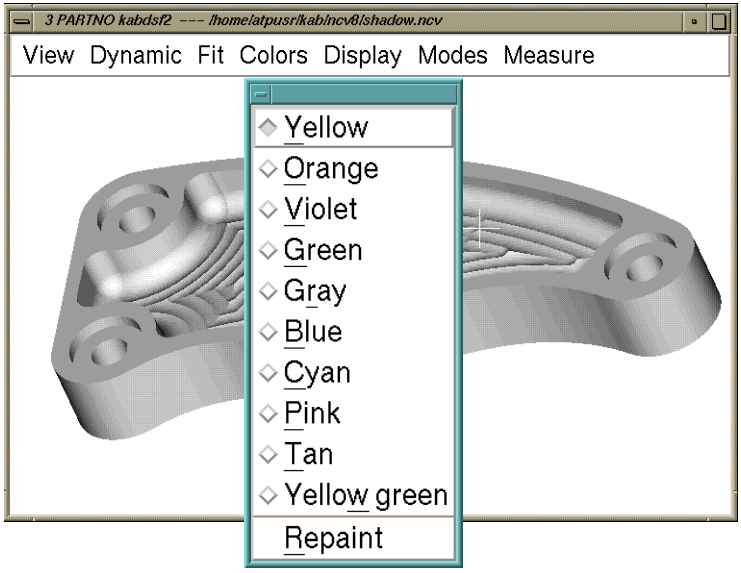


Figure 10-40 The **Colors** menu

The color buttons are used to select the color of the cuts during simulation. The active color button is toggled. First Cut automatically cycles through all colors at each cutter change when the automatic option ❑ Change cut color at cutter change is active; for more on this option, see “The Change color at cutter change Switch,” on page - 37.

To change the current color, simply select it.

The *Repaint* button is used to manually repaint the color of all cut stock to the current color. To repaint cut stock automatically, see “The Change color at cutter change Switch,” on page - 37, and “The …and repaint Switch,” on page - 37.

To change all the cuts to a new color:

1. Toggle one of the color buttons.
2. Select *Repaint.*

Display Menu

Selecting **Display** from the *Geometry Window* displays this menu:

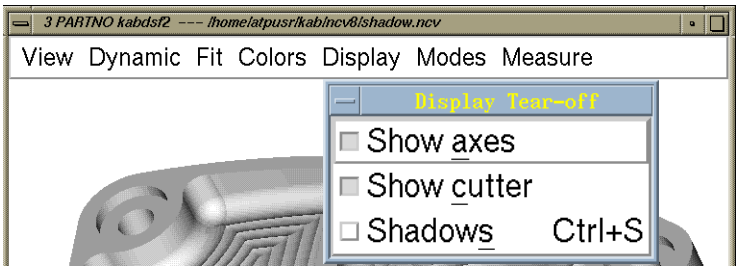


Figure 10-41 The **Display** menu

The Show axes Switch

When this is switched on, the coordinate axes are displayed at the origin and at the top left hand corner of each window.

The Show cutter Switch

When this is switched on, the cutter is displayed. The simulation runs slightly faster if the cutter is not displayed.

The Shadows Switch

Switching this on displays shadows in the window.

Displaying shadows can be useful for highlighting features on the part, and for understanding detail, but is much slower than other display modes.

NOTE	Shadows are displayed only if the light source has been moved away from the line of sight.

Modes Menu

Selecting **Modes** from the *Geometry Window* displays this menu.

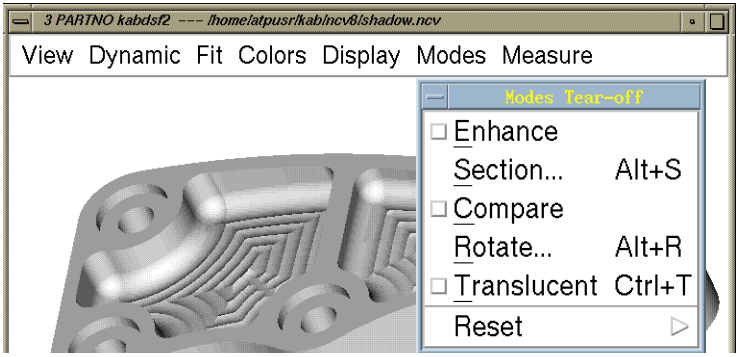


Figure 10-42 The **Modes** menu

The Enhance Switch

Switching this on draws a dark line where the edge of one part of the model lies in front of another. This is especially useful where two parts of the model are rendered at the same brightness, making the edge between them invisible. Switching off returns the image to its unenhanced state.

The *Section...* Selection

You can section the part at any time, or run a simulation while the part is sectioned. To do this, select *Section...* from your **Modes** menu, which displays the Section dialog window:

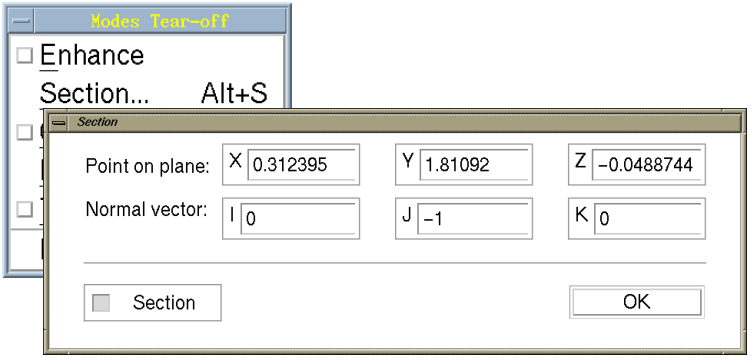


Figure 10-43 The Section panel

The section plane is created by clicking at the desired point on the model, as was done in this illustration, and by typing in the plane's normal vector. You can also type in point coordinates.

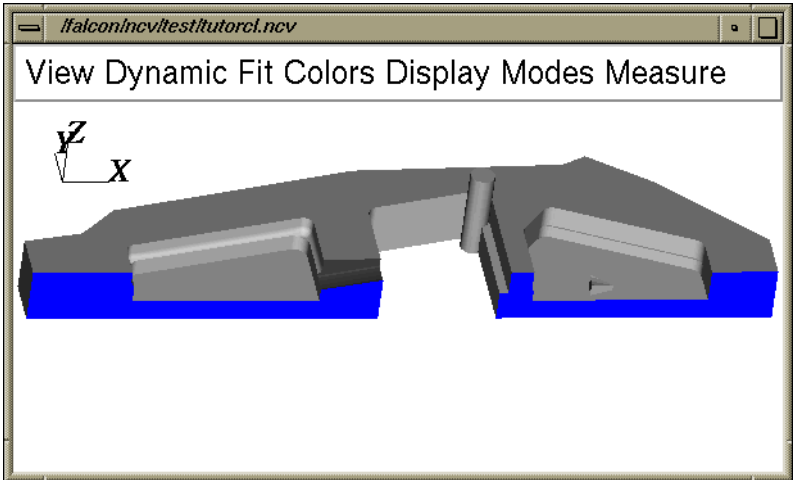


Figure 10-44 A section plane

Reset section and *Reset all*, on the **Modes** menu, restores the image of the complete model.

The Normal vector points in the direction of the material to be made invisible. In the case illustrated, everything with a Y coordinate less than 1.81092 will be made invisible.

You can cancel the dialog window, without turning off sectioning, by selecting the *OK* button.

The Compare Switch

The Compare function is used to compare the as-designed part with the as-machined part. The "as-designed" model of the part must be read in from an SLA file before starting the simulation and may have to be translated, rotated, and scaled to match the coordinate system of the NC program.

To do the comparison, switch on ❑ Compare from the **Modes** menu in the *Geometry Window*.

The part is redrawn in a translucent light-gray color; overcuts (i.e., gouges) are drawn in red; undercuts are drawn in blue. To return to normal display, select the Compare button again.

In comparison mode, the image can be flipped or zoomed, but not rotated.

NOTE All *Geometry Window*s change to comparison mode, and back, together.

The *Rotate…* Selection

The Rotate dialog allows you to swivel the part model about its vertical or horizontal axis, in order to see the part from different angles.

Select the **Modes** button in the *Geometry Window*, and then select *Rotate...*. This will display the Rotate Shaded Image dialog:

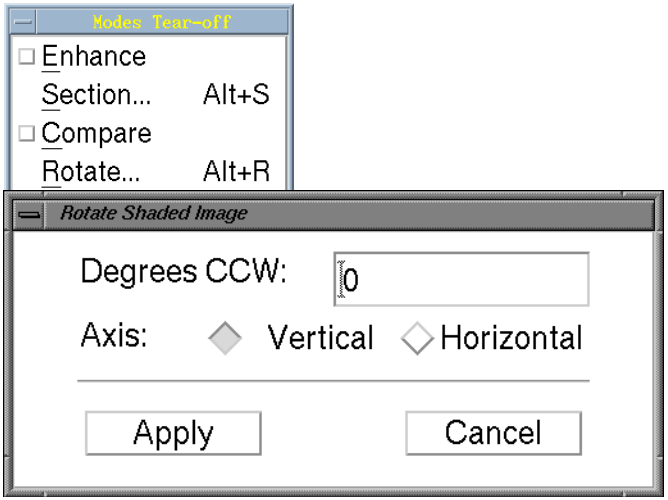


Figure 10-45 The Rotate Shaded Image panel

To rotate the part:

Step 1: Enter the number of degrees, negative if you wish, that you want the part to be rotated. The number of degrees is always taken as absolute, and not as an increment or decrement to any previously entered number.

For vertical rotation, a positive angle causes the front of the part to move to the right, and a negative angle causes it to move to the left. For horizontal rotation, a positive angle rolls the front downwards, and a negative rolls the front upwards.

Step 2: Select *Apply*.

Step 3: Select *Cancel*, or select *Reset all* or *Reset rotation* from the **Modes** menu, to restore the original image.

The Translucent Switch

The stock and fixtures can be displayed translucently in simulation mode, including while the simulation is running. This is especially useful for watching the machining of holes and deep pockets, and of features on the back of the part. To toggle this mode on and off, use the ❑ Translucent switch in the **Modes** menu.

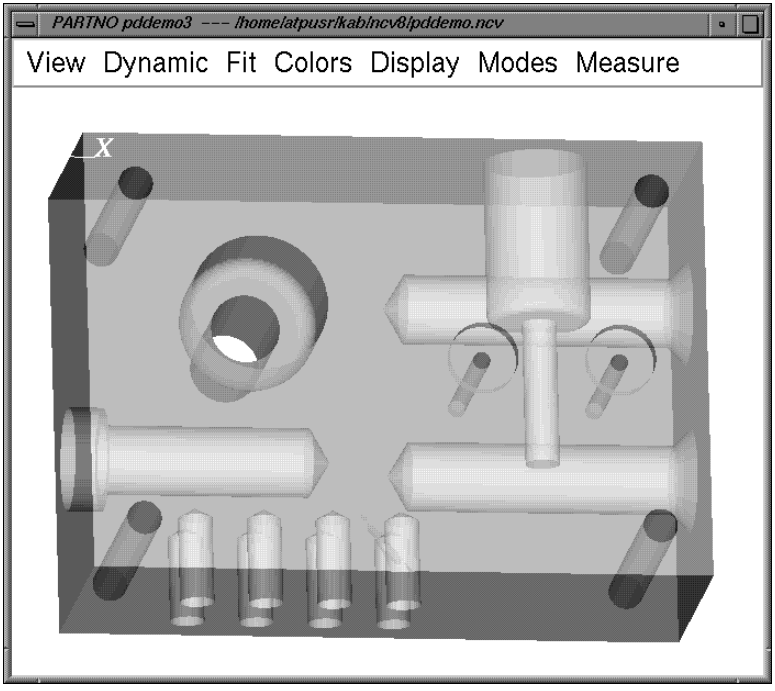


Figure 10-46 Switching on ❑ Translucent

The *Reset* Selections

To restore the default viewing options for sectioning, rotation, zooming or lighting, select the *Reset* button from the **Modes** menu. This displays the *Reset* menu:

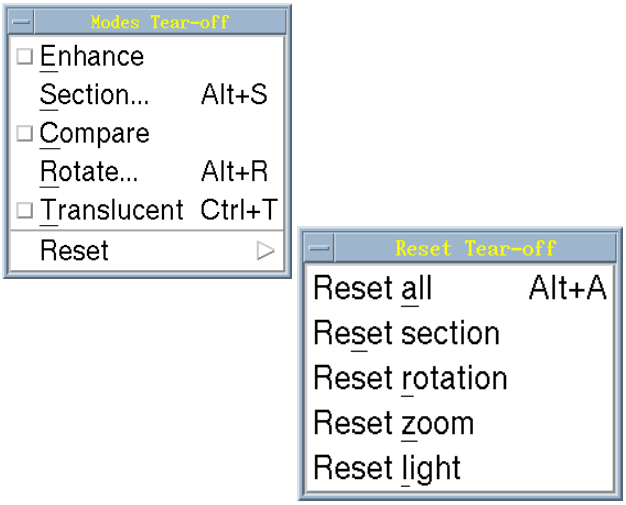


Figure 10-47 The *Reset* menu

Selection	Description
Reset all	Resets sectioning, rotation, zoom, and light source.
Reset section	Restores the full view of the part.
Reset rotation	Returns the view to its original orientation.
Reset zoom	returns the view to its original unzoomed state.
Reset light	Returns the light source to its default direction.

Table C-1 *Reset* selections

Measure Menu

The **Measure** menu is used to take measurements on the model, to obtain a reading of machining times, and to remove chips of material for a better view of the cut part. The **Measure** menu is invoked from the *Geometry Window*:

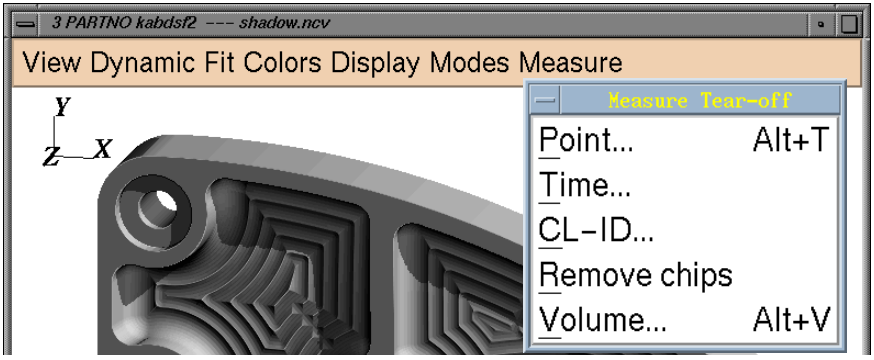


Figure 10-48 The **Measure** menu

The individual functions are explained below.

The *Point...* Selection

Selecting *Point...* from the **Measure** menu gives you the Measure Point dialog window:

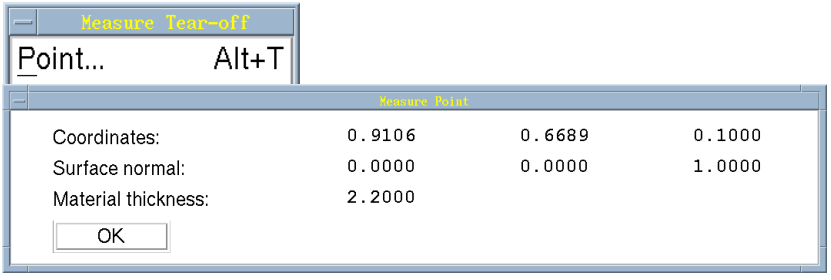


Figure 10-49 The Measure Point panel

The dialog displays precise, rather than approximate, coordinates of the point being measured. It also displays the precise surface normal (the direction perpendicular to the surface) and the precise material thickness.

If you measure cuts such as those above then approximate, rather than precise, coordinates are displayed, and the dialog label changes from "Coordinates:" to "Coordinates (approx):". Also, no surface normal or material thickness are displayed.

If, when determining the material thickness, First Cut finds that the other side of the wall was created by such a cut, the thickness displayed is only approximate, and the label changes from "Material thickness:" to "Material thickness (approx):".

Measurements can be taken when the window is zoomed or sectioned, but not when it is rotated.

This function has these restrictions:

- It does not work on 5-axis cuts, i.e., cuts in which the cutter axis changes from one CL-point to the next.
- It does not work on circular-interpolation cuts (G02, G03, and the CALL/CXCIR macro), since First Cut approximates these internally as a series of linear cuts.
- It does not work on cuts produced by ramping a filleted cutter.

The *Time...* Selection

Selecting the *Time...* button displays the following dialog:

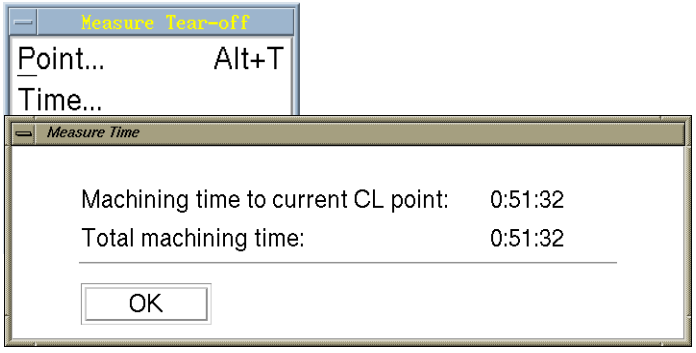


Figure 10-50 The Measure Time panel

Machining times displayed are established as follows:

- The display is of the machining time from the beginning of the current file to the current CL point and the total machining time calculated for the file. If simulation has not been started, the current time is zero; if simulation has completed, the current time equals the total time.
- The calculations assume that all feedrates in the input file are expressed in the same units, i.e., inches or millimeters, and that the coordinate system is in the same units.
- The times include only cutting motions, i.e., they do not take into account RAPID motions, tool changes, or manual operations.

The *CL-ID...* Selection

To identify the cutter and tool-path motion that cut a particular point, select *CL-ID...* from the **Measure** menu, and you will get the following dialog:

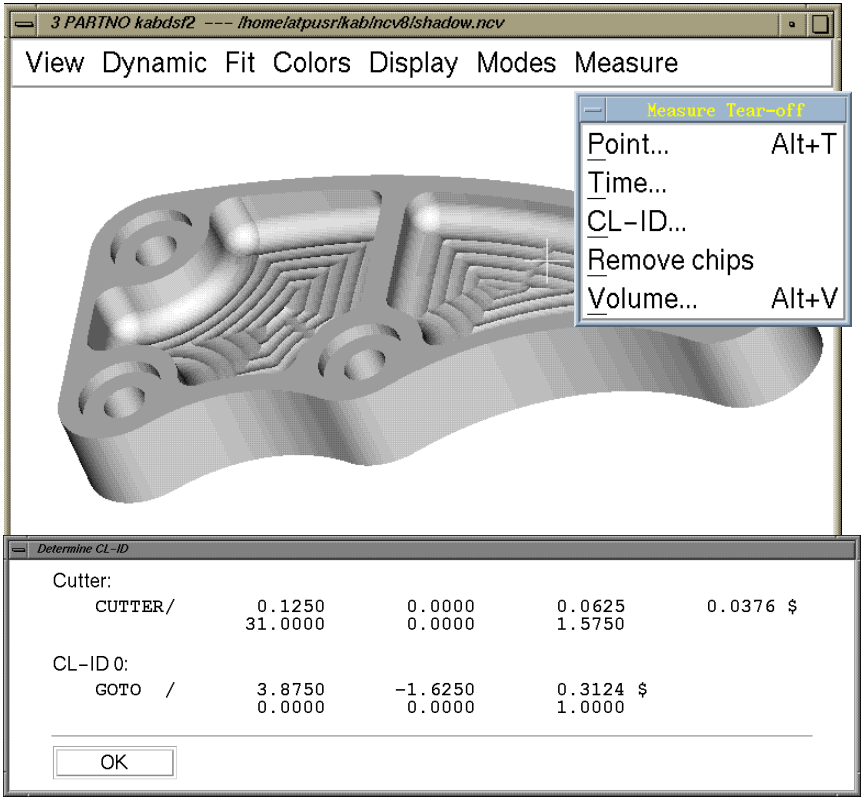


Figure 10-51 The Determine CL-ID panel

- The cutter description is displayed as a **CUTTER** statement for APT cutters and as a **PPRINT/FORM** statement for form cutters.
- The motion is displayed as a **GOTO** statement showing the point's X, Y, Z, and I, J, K coordinates.

You can select (click) at any point on the model, and the CL-ID of the motion that cut that surface will be displayed.

The *Remove chips* Selection

To remove material separated from the view of the part:

First, select the part by clicking on it with the left mouse button.

Then, from the *Geometry Window*'s **Measure** menu, select *Remove chips.*

While the removal calculation is underway, the part will be shaded in red to show progress.

Chip removal is done only in the *Geometry Window* in which you selected the piece. If you wish, you can repeat it for other *Geometry Window*s.

If you have activated a viewing mode (rotation, enhancement, zooming, sectioning, or comparison) in the *Geometry Window*, then you will be asked to reset the view and then remove the chips.

The *Volume...* Selection

To measure the volume of the cut part and of the material removed, choose *Volume...* from the **Measure** menu.

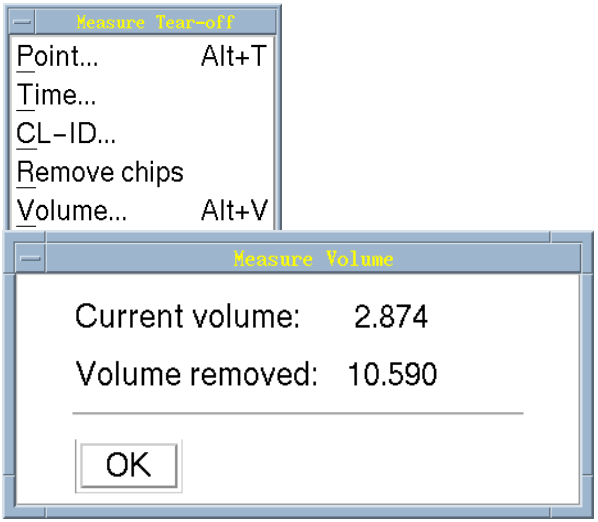


Figure 10-52 The Measure Volume panel

There are several things to keep in mind when using these numbers:

- The stock must be entirely within the window when the simulation begins. Anything outside the window will be silently ignored by the volume calculations.
- If there are chips remaining in the window, they are counted as part of the part volume. To remove them from the calculation, you must remove them from the window; choose *Remove chips* from the **Measure** menu.

With regard to accuracy:

- The numbers are estimates. No uncertainty figures are displayed because there is actually no bound on the possible error. Since First Cut only samples the

part surfaces at each pixel, it has no way of knowing how rough the surfaces are, and how much volume is contained, between pixels.

- However, for a part which you as the user know to be smooth, it is possible to estimate the likely error (for this purpose, both the **`tutorcl`** and clevis tutorial parts can be considered smooth).
- If no stock faces are seen edge-on, i.e., you have avoided *Front* view, *Side* view, etc., you can expect an error on the order of one part in W, where W is the width of the part on-screen in pixels. The default window width is 600 pixels, so if your smooth part fills the window, the error would be one part in 600. If several faces are seen edge-on, the error will be roughly three times this, or three parts in W. If you know your part contains small details that are not captured in First Cut's pixel-based solid model, we suggest you avoid calculating the volumes altogether, because there is no way to know how accurate they are. These accuracy considerations are true of all pixel-based verification products.
- The volume calculation ignores the fixtures and as-designed part, if they are present. To measure the volume of one of these, you can change its type to Stock, go to Simulation mode, and measure the volume. However, remember that First Cut uses polygonal approximations of the as-designed part and fixtures. The volume of the as-designed part in particular is dependent on the quality of the SLA file given to First Cut.

Conclusion

This completes the description of the on-screen functions of First Cut.

Chapter 3 provides a self-teach tutorial, which you can use both to become familiar with the operation of the system and to exercise many of the functions above.

Getting the Most From First Cut

This section describes ways to maximize productivity of First Cut.

Performance

The performance of First Cut is not affected by model complexity. The time taken to simulate the last cut in a ten-thousand-point CL file is typically identical to the time taken for the first cut.

The size of the cutter image on the screen affects simulation performance: the larger the cutter image, the longer it takes to simulate a given CL file, simply because there is more time required for drawing the material cuts and the cutter movements. For example, a view at half scale is generated four times as fast as one at full scale.

The cutter and holder display can be turned on and off. Simulation performance gets faster if solid display is turned off, and much faster if holder display is turned off; however, note that turning off holder display disables holder collision checking. Turning off wireframe cutter display effects only a slight change.

The simulation time increases somewhat with the value of NSIDES, the number of straight line segments used to approximate the circular cross section of the cutter.

Choosing the Continuous display of cutter option reduces performance by 4-12 times for three-axis motion and 8-24 times for five-axis motion using ball end cutters.

If you run other programs on the same workstation, at the same time you are running First Cut, then the extra workload on the machine will slow down First Cut.

Choosing an Optimal View

When simulating very large files, an initial session should be performed at a small scale, with the view (or views) taking up a small proportion of the screen. The result can help define the critical areas and thereby determine more optimal view orientations for subsequent, large scale simulations.

Accuracy

As with all graphical displays, the simulation is an approximation of accurate model data. The larger the model appears on the screen, the more accurate the simulation—and the slower it runs.

Multiple Viewports

If you have a large part or one where there is a lot of fine detail, using multiple viewports may help. In one of the viewports display a complete view of the part, and in other viewports zoom the view up to give you the resolution you require on smaller regions of the part. The complete view of the part enables you to orient yourself to the other views while the simulation is running.

Using this technique it has been possible to verify the tool path for a 20 foot aircraft spar where some of the cuts are only 300ths of an inch deep.

File Management

Files that are no longer needed for current production should be deleted or archived. This especially applies to work-in-process files which consume a great deal of disk space. Core files from system crashes are also large and should be removed immediately.

Dithering

First Cut dithers its shaded images. This eliminates the color bands on objects and makes them appear as smooth as they actually are. An advantage of this scheme is that First Cut can get by allocating fewer colors from the global colormap if necessary, and conversely it can take advantage of more colors if they are available.

There are two costs associated with dithering. The first is a performance penalty of a few percent. The other is the fact that surfaces have a slightly textured appearance. In normal circumstances, i.e., if First Cut can allocate most of the colormap, the texturing is so subtle as to be invisible. However, if First Cut can only allocate a few colors, the texturing is more noticeable. If the texturing is objectionable and a clearer view of the part is desired, you can save either a WIP file or a playback file, restart First Cut with more colors (by first killing other applications), and redisplay the files. The images will be redithered, with more colors and less texture. This trick does not work with **`.xwd`** files, since they are simply records of the pixels on the screen, after dithering has been done.

At one time, if First Cut couldn't allocate enough colors from the global colormap, it would create its own colormap. This allowed First Cut to run even if there were no colors available, but it caused the screen to flash so violently that most users considered it a bug. First Cut now never allocates its own colormap; it deals with limited colors by gracefully degrading the dithering; however this means it has a minimum number of colors it requires from the global colormap. Previous releases could operate without allocating colors from the global color map.

Getting the Most from the CL File Conversion Program

The First Cut product verifies data contained in a CL file. The CL file represents output from an NC processor. Chapter 8 provides the ASCII NCV file format needed by customers whose CL files are not in the format required by NCV. All that is required for a CL file converter is a

utility which dumps programs in a human readable format. Such a utility typically requires few changes to format NC files suitable for use by First Cut.

Cutter Definitions

It is common practice for APT programmers to define 'false' cutters. Although the use of these cutters results in the correct GOTO points, they do not accurately reflect the physical cutter. First Cut allows you to override these false tool definitions using the PPRINT TRUE C statement; this statement is interpreted identically to the word CUTTER and generates a physical tool change. The PPRINT statement is edited into the APT source file after the CUTTER/ statement it overrides. Alternatively, the NCV file can be edited to correct the cutter statement. The statement is formatted as follows:

```
PPRINT TRUE
C/d,r,e,f,alpha,beta,h
```

The parameters conform to the APT seven-parameter cutter definition convention. If a parameter has no value assigned, a zero must be used as a place holder.

Physical Tool Changes

Two conditions are interpreted as physical tool changes: A **PPRINT TRUE C** statement and a **CUTTER** statement immediately after a line containing one of the following major words:

LOADTL, TOOLNO, TURRET or TMARK

CUTTER statements that occur in one or more lines after a physical tool change statement, but which are not themselves preceded by one of these major words are ignored.

For example,

If the first lines of an NCV file contain this sequence:

CUTTER,
FROM,
GOTO,
LOADTL,

CUTTER,
FROM,
GOTO,
CUTTER

then the first and second cutter definitions would be recognized, but the third one would be ignored.

When a physical tool change occurs immediately before a **GOTO** statement, the **GOTO** is treated like a **FROM** statement because most machines automatically retract the spindle to allow the tool to be changed. Therefore, a sequence of statements such as

LOADTL, CUTTER, GOTO x, y, z, i, j, k

will be treated the same as

LOADTL, CUTTER, FROM x, y, z, i, j, k

Post Processor Statements

Cycle statements are not simulated. See “Major Word Table” on page 7-3 for a list of supported major and minor words. Major words that are not recognized are ignored.

Converting a CL File (cltoncv)

The CLTONCV converter program is called cltoncv. It converts a binary CL file into an ASCII format (which is the NCV file) for input to the NCV program. A custom CL file converter must be developed if the input file is not a standard IBM APT-AC or 360 CL file. For a binary CL file generated from CATIA, an extra parameter is added to the command line to define the type of processing required.

The output NCV file format is described in “NCV File Format Specifications for Custom CL File Conversion” on page 7-1, and an example of the NCV format is shown in “Sample NCV File” on page 7-39.

The converter will automatically detect an APT-AC or 360 CL file and process it accordingly. If the format is not recognized the user will be prompted for the block size, assuming that the block size is the difference. When the block size is entered it is stored in a file called **`ncv.config`**. The user will not be prompted again unless the ncv.config file is deleted. Editing the ncv.config file will also allow the block size to be changed.

The control file, used for processing defaults in earlier versions of NCV, is optional. Stock and fixture geometries, can be defined interactively. Control files used with previous releases, however, can still be used as part of the CL file conversion process. For more information on control files, see "The Control File Option" on page 10-69.

File Conversion Program cltoncv

The CL file and the control file are combined and converted to the format used by the simulation program by the file conversion program (**`cltoncv`**).

For more information on control files see "The Control File Option" on page 10-69 and "Sample Control File" on page 7-42.

To execute the program that converts the CL file, key in:

cltoncv tutorcl tutorct <RETURN>

where **tutorcl** is the name of the cl file, and **tutorct** is the control file. For CL files from CATIA, a "**-w**" parameter is added to the command line, for example:

cltoncv -w tutorcl tutorct

The following illustration shows a typical sequence of actions:

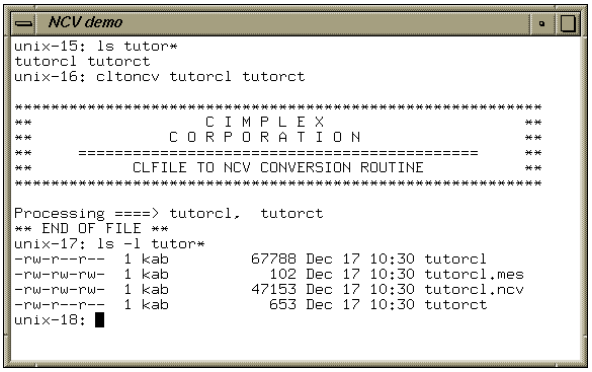

NCV demo
unix-15: ls tutor*
tutorcl tutorct
unix-16: cltoncv tutorcl tutorct
****
** C I M P L E X **
** C O R P O R A T I O N **
** ========== **
** CLFILE TO NCV CONVERSION ROUTINE **
****
Processing ====> tutorcl, tutorct
** END OF FILE **
unix-17: ls -l tutor*
-rw-r--r-- 1 kab 67788 Dec 17 10:30 tutorcl
-rw-rw-rw- 1 kab 102 Dec 17 10:30 tutorcl.mes
-rw-rw-rw- 1 kab 47153 Dec 17 10:30 tutorcl.ncv
-rw-r--r-- 1 kab 653 Dec 17 10:30 tutorct
unix-18:

Figure 10-53 The file conversion program

In the illustration, you will see that the directory contents have been listed, and then the command has been keyed in. If you do not key in the CL filename and the Control File name, you will be prompted for the filenames.

First Cut displays a text banner message during the conversion. The files in the directory after the conversion have also been listed, showing the new ones generated, and these are explained below. When the conversion is complete, you are returned to the UNIX prompt.

The NCV File and MES File

The **CLTONCV** conversion program creates two output files in our illustration on the preceding page: **tutorcl.ncv** and **tutorcl.mes**. The **ncv** file contains the converted data which is the input file for the simulation program. The NCV file has the format **[clfilename].ncv**. An example of an NCV file is given in “Sample NCV File” on page 7-39.

The other output file, **tutorcl.mes** in our illustration, contains messages generated by the conversion process. It is called the MES file and has the format **[clfilename].mes**. A MES file would read something like this:

```
APT-AC CLFILE DUMP UTILITY LISTING
' INPUT OPTIONS '
```

```
BOX_TYPE='SPECIFIED' DEFAULT_CUTTER='';
' NO DUMP OPTION SPECIFIED - CLFILE_TO APT_SOURCE
ASSUMED '
' default cutter height <= 0, minimum_cutter_length used '
NUMBER OF CLPOINTS = 470
```

The Control File Option

Processing defaults can be selected directly from the menus or by using the control file option, described here. The control file includes

- Stock and Fixture Definitions (a stock definition is mandatory for NCV. Fixture definitions are optional)
- Cutter Default Parameters
- Other Processing Defaults

Syntax for Each Control File Definition

Variable names are in uppercase. Each variable name is followed by an equal sign (=) and the actual value of the variable, for example XC=39.2. Each variable and value combination is separated by a comma (,). The last variable and value combination in the control file is followed by a semicolon (;). An example control file is shown in "Example Control File" on page 10-75.

Stock Definition

Stock can be defined in several ways: specified box, auto box, and profile sweep. Only one stock definition can be included per file.

Stock Box (specified)

Syntax:

```
BOX_TYPE='SPECIFIED',XC=[a],YC=[b],ZC=[c],
LENGTHX=[d],WIDTHY=[e],HEIGHTZ=[f]
```

This box statement specifies the coordinates for the center of the stock box, XC, YC, ZC, and the overall length, width, and height of the stock box, LENGTHX, WIDTHY, HEIGHTZ.

Stock box - Auto

Syntax

BOX_TYPE='AUTO'

The box is automatically created by the system as the bounding box of the CL points. This is useful as an approximation to the actual stock when the dimensions of the actual stock are not known.

Stock Profile Sweep

Syntax

PROFILE_TYPE='SPECIFIED',
NUMBER_OF_PROFILE_POINTS=[a],
SPCX=[b],SPCY=[c], SPCZ(),SPTHCK=[d],
SPX(1)=[e],SPY(1)=[f],
SPX(2)=[g],SPY(2)=[h],
.....
SPX(a)=[i],SPY(a)=[j],

The profile sweep statement specifies the total number of points required to create the profile of the stock polygon. The coordinates for the origin of the stock polygon, **SPCX**, **SPCY**, **SPCZ**, the thickness of the stock, **SPTHCK**, and the XY coordinates of each point in the profile, **SPX(n)** and **SPY(n)** must all be specified. NCV closes the profile by connecting the last defined pair of coordinates with the first defined pair of coordinates.

To create profile sweeps in arbitrary directions give the **PROFILE_TYPE** as **'VECTOR'** and omit the **SPCX**, **SPCY**, **SPCZ** and **SPTHCK** items and specify the start and end points using **STPX**, **STPY**, **STPZ**, **ENPX**, **ENPY** and **ENPZ**.

Fixture Definition

One kind of fixture can be defined: box.

Fixture Box

Syntax

BOX_TYPE='FBOX',XC=[a],YC=[b],ZC=[c],
LENGTHX=[d],WIDTHY=[e],HEIGHTZ=[f]

This box statement specifies the coordinates for the center of the fixture box, XC, YC, ZC, and the overall length, width, and height of the fixture box, LENGTHX, WIDTHY, HEIGHTZ.

Syntax

FCX(1)=[a],FCY(1)=[b],FCZ(1)=[c],
FLX(1)=[d],FWY(1)=[e],FHZ(1)=[f],
.....
FCX(n)=[u],FCY(n)=[v],FCZ(n)=[w],
FLX(n)=[x],FWY(n)=[y],FHZ(n)=[z],

The fixture box definition specifies the coordinates for each fixture box. The coordinates for the center, **FCX(n)**, **FCY(n)**, **FCZ(n)**, and the length, width and height, **FLX(n)**, **FWY(n)**, **FHZ(n)** must also be specified. Multiple fixture definitions can exist in a control file.

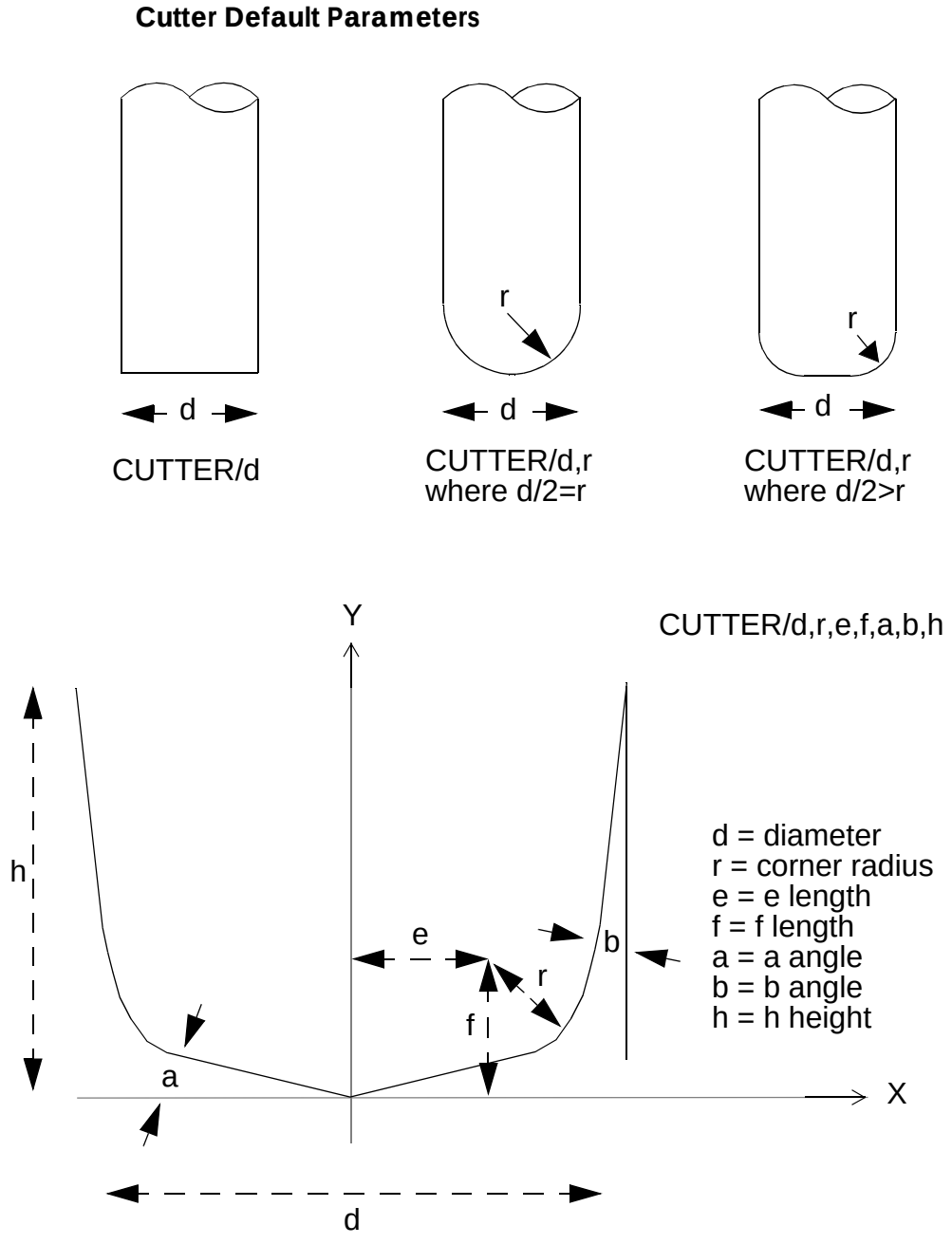


Figure 10-54 Cutter and geometry parameters

Cutter Default Definition

Syntax

DEFAULT_CUTTER='SPECIFIED',
DC_D=[d],DC_R=[r],DC_E=[e],DC_F=[f],
DC_ALPHA=[a],DC_BETA=[b],DC_H=[h],

This statement defines the parameters of the default cutter added to the NCV file when motion is found without a CUTTER statement. The default cutter will be used until the next CUTTER statement is found. The default cutter is defined by the values DC_D, DC_R, DC_E, DC_F, DC_ALPHA, DC_BETA, DC_H, conforming with the APT seven-parameter cutter definition convention.

Cutter Types

One type of non-standard cutter definition is allowed. The fillet radius R is allowed to be greater than half the diameter D. For such cutters the A and B angles must be zero, and the F parameter must be equal to R.

Minimum Cutter Diameter Default

Syntax

MINIMUM_CUTTER_DIAMETER=[a],

Minimum Cutter Length Default

Syntax

MINIMUM_CUTTER_LENGTH=[a],

The minimum cutter length and diameter buttons allow the user to specify a default value to override the programmed length and/or diameter. If a cutter with a length or diameter smaller than the minimum value is encountered during conversion, the default value is substituted for all tool motion points that follow, until the next cutter statement is encountered. The minimum cutter length and diameter tests are applied to all valid cutter statements and PPRINT TRUE C statements encountered during the simulation.

Processing Defaults

Tool Axis Default

Syntax

TOOL_AXIS='SPECIFIED',TAI=[a],TAJ=[b],TAK=[c],

Defines the tool axis used during simulation when the axis is not explicitly specified in the input file, e.g., in a three-axis file or after a MULTAX OFF statement. The values for I, J, and K are specified, TAI, TAJ, TAK.

Feedrate/RAPID Override

Syntax

MAX_FEED=[a],

This value specifies the maximum value which the FEDRAT statement considers a cutting feedrate. If FEDRAT is greater than this value, a RAPID * statement is inserted in the NCV file.

Cutter Facets

Syntax

NSIDES=[a],

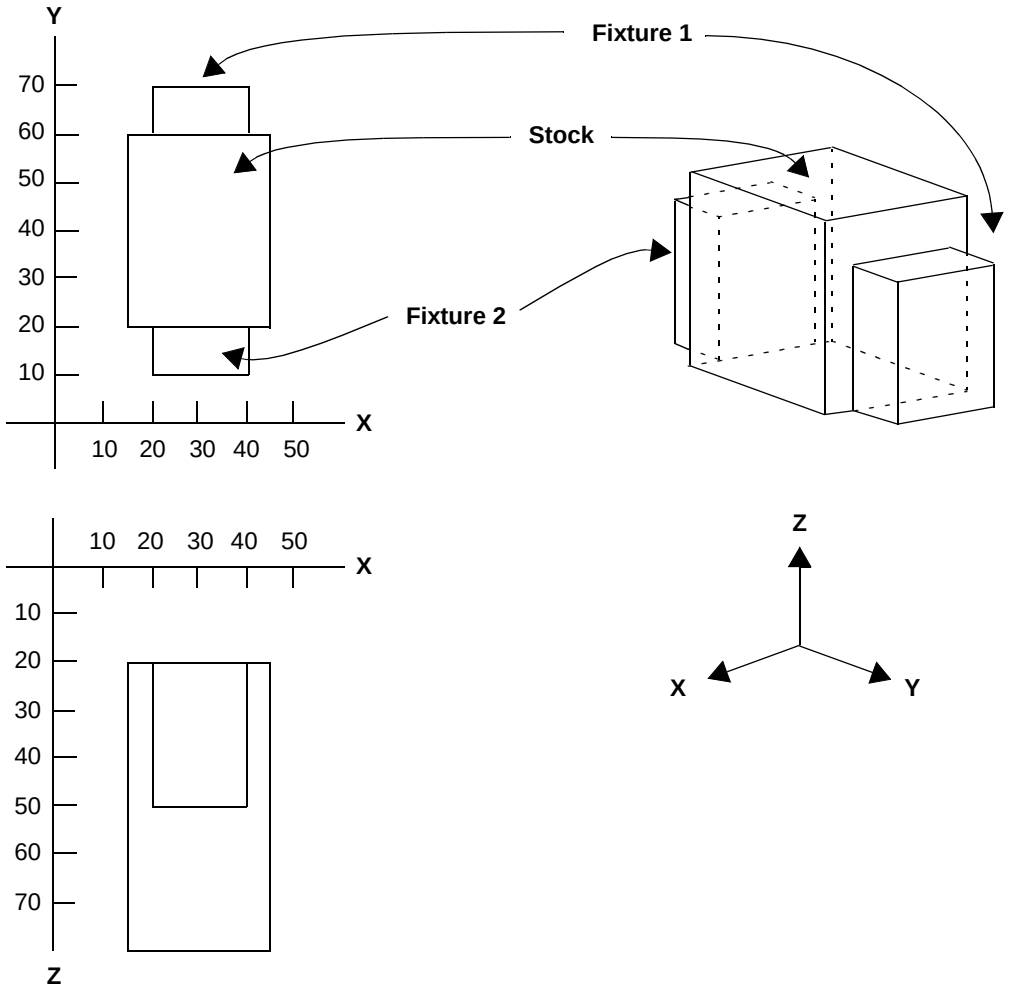
This value specifies the number of facets around the circumference of a cutter to be used in approximating its surface. Increasing the number of facets improves the resolution of the screen, but substantially increases the time required to process a file. The default value is twelve (12). The recommended range is between six (6) and thirty two (32).

The number of facets across the fillet is controlled by NSIDES. A 90 degree fillet (A and B angles of zero) would have NSIDES/4 facets, so the default NSIDES of 12 will give 3 facets.

Example Control File

The following is an example of a control file. The stock and fixture defined in the control file are shown below.

```
BOX_TYPE = 'SPECIFIED', XC = 30, YC = 40, ZC = 50,
LENGTHX = 30, WIDTHY = 40, HEIGHTZ = 60,
FCX(1)=30, FCY(1)=65, FCZ(1)=35,
FLX(1)=20, FWY(1)=10, FHZ(1)=30,
FCX(2)=30, FCY(2)=15, FCZ(2)=35,
FLX(2)=20, FWY(2)=10, FHZ(2)=30,
DEFAULT_CUTTER='SPECIFIED',DC_D=1.0,DC_R=.25,
DC_E=.25,DC_F.25,DC_ALPHA=0,DC_BETA=0,DC_H=5,
MINIMUM_CUTTER_DIAMETER=.1,
MINIMUM_CUTTER_LENGTH=1.000,
TOOL_AXIS='SPECIFIED', TAI=0, TAJ=1, TAK=0,
MAX_FEED=100.0, NSIDES=12;
```



Stock and fixture sketch

NCV Input Data Formats

This chapter deals with the input format specifications and examples as follows:

➢ “NCV File Format Specifications for Custom CL File Conversion” on page 10-77
➢ “Major Word Table” on page 10-79
➢ “CYCLE Words” on page 10-97
➢ “Sample NCV File” on page 10-114
➢ “Sample Control File” on page 10-117
➢ “Sample Stock Definition in NCV File” on page 10-118
➢ “SLA File Format” on page 10-118
➢ “G-Code Input” on page 10-120
➢ “CATIA File Input” on page 10-124
➢ “Tool Holders” on page 10-125

NCV File Format Specifications for Custom CL File Conversion

Basic Structure for File Formats

In the NCV file, each line contains a major word and parameters. The format matches APT. The basic structure is

- Major words can be upper or lowercase.
- Major words and their parameters must be separated by blanks, slashes(/), or commas(,).
- There are no fixed format restrictions on line length or character position.
- The first parameter in each line is the CL-ID; it is followed by the major word. It is optional. The CL-ID specifies the line number shown in the CL print.

- To specify the range of points to be verified, the CL-ID for **GOTO** and **FROM** motions must always increase from one line to the next. The CL-ID need not increase in increments of one. Therefore, the sequence 10, 21 would be valid; but 10, 9 would not.
- **REMARK** statements are ignored.
- Lines beginning with "**$$**" are ignored.
- Continuation lines, i.e. lines ending in "**$**", are handled.

Numeric Convention

The Major Word Table, in the next section, defines the value types that precede and follow each major word, using the following syntax:

float	whole number, decimal number, or scientific notation number
integer	whole number
char	character string

Take, for example, the following declaration:

CUTTER

Format	**integer char float float float float float float float**
Use	Defines the tool.
parm 1	CL record number
parm 2	**'CUTTER'**
parm 3-9	APT cutter parameters (**d r e f a b h**)

NCV recognizes the major word **CUTTER** and uses it to define the cutting tool. NCV expects this word to be the second major word on the input line and to be followed by the seven floating point numbers which define an APT cutter. For example:

```
84 CUTTER 1.0 0.12000 0.380 0.120 0.00 0.00 5.000
```

Major Word Table

$$

Format	**integer char char**
Use	Comment line.
parm 1	CL record number
parm 2	**'$$'**
parm 3	Comment string of characters and spaces.

BOX

Format	**integer char float float float float float float**
Use	Defines a stock box using center point and dimensions.
parm 1	CL record number - ignored.
parm 2	**'BOX'**
parm 3-5	Box center: X, Y and Z coordinates.
parm 6-8	Box dimensions: **LENGTHX**, **WIDTHY**, **HEIGHTZ**.

BREAK

Format	**integer char**
Use	Stops simulation at next CL point.
parm 1	CL record number
parm 2	**'BREAK'**

CALL/CXCIR or CALL/ATPCIR

Format	**integer char char**
Use	Calls to the First Cut Circular Interpolation Macro.
parm 1	CL record number
parm 2	**'CALL/ATPCIR'** or **'CALL/ATPCIR'**
parm 3	String of characters, passing the following **ATPPPX = ppx, ATPPPY = ppy, ATPPPZ = ppz, $** **ATPSPX = spx, ATPSPY = spy, ATPSPZ = spz, $** **ATPMPX = mpx, ATPMPY = mpy, ATPMPZ = mpz, $** **ATPEPX = epx, ATPEPY = epy, ATPEPZ = epz, $** **ATPCCX = ccx, ATPCCY = ccy, ATPCCZ = ccz** where: **(ppx,ppy,ppz)** is the previous point (can be **(0,0,0,)**) **(spx,spy,spz)** is the start point **(mpx,mpy,mpz)** is a point on the arc **(epx,epy,epz)** is the end point **(ccx,ccy,ccz)** is the center point

CBOX

Format	**integer char float float float float float float**
Use	Defines a stock box using two corners.
parm 1	CL record number - ignored.
parm 2	**'CBOX'**
parm 3-5	Box corner no. 1: X, Y and Z coordinates.
parm 6-8	Box corner no. 2: X, Y and Z coordinates.

COOLNT

Format	**integer char char char**
Use	Specifies coolant flow.
parm 1	CL record number.
parm 2	**'COOLNT'**
parm 3	**'FLOOD'**, **'MIST'**, **'ON'**, or **'OFF'**

CUTTER

Format	**integer char float float float float float float float**
Use	Defines the tool.
parm 1	CL record number.
parm 2	**'CUTTER'**
parm 3-9	APT cutter parameters (**d r e f a b h**)

CYCLE

The various forms of this Major Word are given in “CYCLE Words” on page 10-97.

CYL

Format	**integer char float float float float float float float**
Use	Defines a stock cylinder using two axis points and radius.
parm 1	CL record number - ignored.
parm 2	**'CYL'**
parm 3-5	Axis point no. 1: X, Y and Z coordinates.
parm 6-8	Axis point no. 2: X, Y and Z coordinates.
parm 9	Radius.

ENVECT

Format	**integer char float float float**
Use	Alternative header definition for profile sweep. (See “STVECT” on page 10-94 and “SPPROF” on page 10-94.)
parm 1	CL record number - ignored.
parm 2	**'ENVECT'**
parm 3-5	End point of sweep (X, Y, Z).

FBOX

Format	**integer char float float float float float float**
Use	Defines a fixture box using center point and dimensions.
parm 1	CL record number - ignored.
parm 2	**'FBOX'**
parm 3-5	Box center: X, Y and Z coordinates.
parm 6-8	Box dimensions, **LENGTHX**, **WIDTHY**, **HEIGHTZ**.

FCBOX

Format	**integer char float float float float float float**
Use	Defines a fixture box using two corners.
parm 1	CL record number - ignored.
parm 2	**'FCBOX'**
parm 3-5	Box corner no. 1: X, Y and Z coordinates.
parm 6-8	Box corner no. 2: X, Y and Z coordinates.

FCYL

Format	**integer char float float float float float float float**
Use	Defines a fixture cylinder using two axis points and radius.
parm 1	CL record number - ignored.
parm 2	**'FCYL'**
parm 3-5	Axis point no. 1: X, Y and Z coordinates.
parm 6-8	Axis point no. 2: X, Y and Z coordinates.
parm 9	Radius.

FEDRAT

Format	**integer char char float**, or **integer char float**
Use	Specifies the feedrate to be used for subsequent cutter motions.
parm 1	CL record number.
parm 2	**'FEDRAT'**
parm 3	Units: **'IPR'** or **'IPM'** or **'MMPR'** or **'MMPM'**.
parm 4	The feedrate for subsequent tool motions.
NOTE	Parameter 3, units, is optional. The order of parameters 3 and 4 can be reversed.

FINI

Format	**integer char**
Use	Marks the end of the input file to NC Verification.
parm 1	CL record number.
parm 2	**'FINI'**

FROM

Format	**integer char float float float float float float**
Use	Specifies the starting position for the next tool motion. Whatever its current position, the cutter is immediately repositioned to the specified **FROM** point, without sweeping through any of the intervening space.
parm 1	CL record number.
parm 2	**'FROM'**
parm 3-5	X, Y, and Z.
parm 6-8	I, J, and K components of tool axis.
NOTE	The I, J and K components are used only when **MULTAX** is **ON**.

GODLTA

Format	**integer char float float float**
Use	Specifies the next tool motion as an offset from current point.
parm 1	CL record number.
parm 2	**'GODLTA'**
parm 3-5	X, Y, and Z offsets.

GOHOME

See description under “LOADTL, TOOLNO, TURRET, TMARK, GOHOME, STOP” on page 10-86.

GOTO

Format	**integer char float float float float float float**
Use	Specifies the next tool motion. Note that if **MULTAX** is **OFF**, further parameters are treated as more points, e.g., GOTO/X1,Y1,Z1,X2,Y2,Z2, …
parm 1	CL record number.
parm 2	**'GOTO'**
parm 3-5	X, Y, and Z.
parm 6-8	I, J, and K components of tool axis.
NOTE	The I, J and K components are used only when **MULTAX** is **ON**.

LOADTL, TOOLNO, TURRET, TMARK, GOHOME, STOP

Format	**integer char**
Use	Specifies that a physical tool change will occur.
parm 1	CL record number.
parm 2	**'LOADTL', 'TOOLNO', 'TURRET', 'TMARK', 'GOHOME', 'STOP'**
NOTE	If a physical tool change is followed by a **GOTO** statement, this **GOTO** statement is treated like a **FROM** statement, as the NC Verification software assumes that the spindle was retracted to allow the tool change. After the first occurrence of a physical tool change statement, the only **CUTTER** statements that are recognized are those preceded by one of the above major words; all other **CUTTER** statements are ignored. **PPRINT TRUE** C statements are always recognized.

MULTAX

Format	**integer char char**
Use	Specifies whether the I, J, and K components of subsequent **GOTO**s should be used to determine the tool axis, or ignored. IF **MULTAX** is **ON** and no I,J,K components are found an error will be displayed and written to the **`ncver.out`** file.
parm 1	CL record number.
parm 2	**'MULTAX'**
parm 3	APT parameter (**'ON'** or **'OFF'**).

NSIDES

Format	**integer char integer**
Use	Defines number of sides around cutter.
parm 1	CL record number - ignored.
parm 2	**'NSIDES'**
parm 3	Number of sides to approximate cutter.

PARTNO

Format	**integer char char**
Use	Specifies the part number. This number displays at the top of the screen during simulation and is, therefore visible in any slide files that are created.
parm 1	CL record number.
parm 2	**'PARTNO'**
parm 3	A string of characters and spaces which define the part number.

PPRINT

Format	**integer char any_sequence_of_characters**
Use	Provides general notes and override existing cutter statements.
parm 1	CL record number.
parm 2	**'PPRINT'**
parm 3	A comment string, which NCV ignores unless it is one of the forms described below.

PPRINT BREAK

Format	**integer char char**
Use	The use of this statement halts the simulation at this point. Selecting the *Go* button continues the simulation.
parm 1	CL record number.
parm 2	**'PPRINT'**
parm 3	**'BREAK'**

PPRINT COLOR

Format	**integer char char integer**
Use	Specifies the color to be used for the part cuts from this point on in the simulation.
parm 1	CL record number - ignored.
parm 2	**'PPRINT'**
parm 3	**'COLOR'**
parm 4	Color code, from following table:

1	yellow
2	orange
3	violet
4	green
5	gray
6	blue
7	cyan
8	pink
9	tan
10	yellow green

PPRINT HOLDER NAME

Format	**integer char char char**
Use	Specifies the tool holder to be used for a particular cutter. The **PPRINT HOLDER** statement applies to all following **CUTTER** statements until the next **PPRINT HOLDER**. If no name is specified, no holder is used for the affected cutters.
parm 1	CL record number - ignored.
parm 2	**'PPRINT'**
parm 3	**'HOLDER'**
parm 4	Tool holder name - optional.

PPRINT IMAGE

Format	**integer char char**
Use	This statement tells NCV to create a **.xwd** image file at this point in the program.
parm 1	CL record number - ignored.
parm 2	**'PPRINT'**
parm 3	**'IMAGE'**

PPRINT TRUEC (or PPRINT TRUE C)

Format	**integer char float float float float float float float** or **integer char char float float float float float float float**
Use	Defines the tool.
parm 1	CL record number.
parm 2	**'PPRINT'**
parm 3	**TRUEC**
parm 4-10	APT cutter parameters (**d r e f a b h**).

or:

parm 3-4	**TRUE C**
parm 5-11	APT cutter parameters (**d r e f a b h**).

PPRINT WIP NAME

Format	**integer char char char**
Use	This statement tells NCV to write a WIP file at this point in the program.
parm 1	CL record number - ignored.
parm 2	**'PPRINT'**
parm 3	**'WIP'**
parm 4	WIP file name.

RAPID

Format	**integer char char**
Use	Specifies that one or more rapid motions will occur.
parm 1	CL record number.
parm 2	**'RAPID'**
parm 3	**'*'** - this is optional; a RAPID * applies to all **GOTO** points until another RAPID or **FEDRAT** statement is found. Without the star, the RAPID applies only to the next **GOTO**.

REMARK

Format	**integer char char**
Use	Comment line.
parm 1	CL record number.
parm 2	**'REMARK'**
parm 3	String of characters and spaces.

ROTABL

Format	**integer char char float**
Use	Rotates the coordinate system to the specified angle, around the world-space Y axis.
parm 1	CL record number.
parm 2	**ROTABL**
parm 3	**'INCR'** or **'ATANGL'**
parm 4	Specified angle, in degrees, incremental or absolute.

SPINDL

Several formats of the **SPINDL** statement are handled:

Format 1	**integer char char**
Use	Specifies spindle on or off.
parm 1	CL record number.
parm 2	**'SPINDL'**
parm 3	**'ON'** or **'OFF'**

Format 2	**integer char char float**
Use	Specifies the spindle speed.
parm 1	CL record number.
parm 2	**'SPINDL'**
parm 3	**'CLW'** or **'CCW'**
parm 4	Spindle speed in RPM.

Format 3	**integer char float char**
Use	Specifies the spindle speed.
parm 1	CL record number.
parm 2	**'SPINDL'**
parm 3	Spindle speed in RPM.
parm 4	**'CLW'** or **'CCW'** - this is optional.

Format 4	**integer char char float char**
Use	Specifies the spindle speed.
parm 1	CL record number.
parm 2	**'SPINDL'**
parm 3	**'RPM'**
parm 4	Spindle speed in RPM.
parm 5	**'CLW'** or **'CCW'** - this is optional.

SPROF

Format	**integer char float float float float**
Use	Defines head for profile sweep.
parm 1	CL record number - ignored.
parm 2	**'SPROF'**
parm 3-5	Center point (X, Y, Z).
parm 4	Thickness.
NOTE	An example of how to use this is given at “Sample Stock Definition in NCV File” on page 10-118.

SPPROF

Format	**integer char float float**
Use	Defines profile sweep point.
parm 1	CL record number - ignored.
parm 2	**'SPPROF'**
parm 3-4	Profile point (X, Y).
NOTE	An example of how to use this is given at “Sample Stock Definition in NCV File” on page 10-118.

STVECT

Format	**integer char float float float**
Use	Alternative header definition for profile sweep.
parm 1	CL record number - ignored.
parm 2	**'STVECT'**
parm 3-5	Start point of sweep (X, Y, Z).

STOP

See description under “LOADTL, TOOLNO, TURRET, TMARK,

GOHOME, STOP” on page 10-86.

TLAXIS

Format	**integer char float float float**
Use	Specifies the default tool axis to be used when MULTAX is OFF. When MULTAX is ON, the tool axis specified in the FROM or GOTO statement is used.
parm 1	CL record number.
parm 2	**'TLAXIS'**
parm 3-5	Default I, J and K components of the tool axis.

TMARK

See specification under “LOADTL, TOOLNO, TURRET, TMARK, GOHOME, STOP” on page 10-86.

TOOLNO

Format	**integer char char float char** or **integer char**
Use	The **TOOLNO/ADJUST, n, INCR** statement causes each point to be adjusted n units along its axis. Positive n causes an adjustment away from the part, negative n towards the part. An unparameterized **TOOLNO** statement resets the adjustment to zero (see “LOADTL, TOOLNO, TURRET, TMARK, GOHOME, STOP” on page 10-86).
parm 1	CL record number - ignored.
parm 2	**'TOOLNO'**
parm 3	**'ADJUST'**
parm 4	Distance by which to adjust.
parm 5	**'INCR'**

TURRET

See specification under “LOADTL, TOOLNO, TURRET, TMARK, GOHOME, STOP” on page 10-86.

CYCLE Words

CYCLE Formats

NCV accepts **CYCLE** Major Words in the following forms:

```
          ( DRILL     )
          ( FACE      )
CYCLE /   ( TAP       ) , depth, <feedrate> [,clear] [,<options>]
          ( BORE      )
          ( REAM      )

          ( DEEP      )
CYCLE /   ( BRKCHP    ) [, depth, INCR], <steps&feedrates> [, clear] [, <options>]

CYCLE /   THRU, depth, <step_data>, <feedrate> [, clear] [, <options>]

CYCLE /   CSINK, odia, angle [, idia], <feedrate> [, clear] [, <options>]

          ( ON        )
CYCLE /   ( OFF       )
          ( NOMORE    )
```

NCV reports **CYCLE / MANUAL** statements as errors and ignores them.

NCV treats all points between the **CYCLE / type** and **CYCLE / OFF** or **CYCLE / NOMORE** statements as candidates for special cycle processing. The exception is any point preceded by the **RAPID** keyword. RAPID motions during a cycle are considered to be avoidance moves.

The **CYCLE** statements are explained below.

CYCLE Parameters

Cycles have parameters of depth of operation, feedrate, and startup clearance distance.

Depth of Operation

The depth, when required, follows immediately the **CYCLE / type**. It is the distance below each point to which the operation is to perform. A negative depth specifies an end position above the control point; it does not cause a “reverse” operation. The depth value must always result in a position at or below the cycle clearance plane.

Feedrate

The feedrate comprises feed type and the feed value formatted as follows:

IPM, feed value
IPR, feed value
MMPM, feed value
MMPR, feed value

All cycles must specify a feedrate. The **DEEP** and **BRKCHP** may specify multiple feedrates. Feedrate keywords are

KEYWORD	VALUE
IPM	Inches per minute
IPR	Inches per revolution
MMPM	Millimeters per minute
MMPR	Millimeters per revolution

Clearance Height

Clear is the distance above each point at which NCV will position the cutter prior to and after the required operation. “Clear” follows the feedrate parameter.

If no clear value is specified, the last clear value given is used. The default clearance value on the first cycle statement is zero. A negative clearance specifies a start position below the control point; it does not cause a “reverse” operation. The clearance value must always result in a position at or above the cycle depth (or first cycle step).

Common Options

There are options available to cause additional processing at each point. These options must follow the general syntax (i.e., after the depth, feedrate and clearance parameters) and can be coded in any order. Not all options apply to all cycle types. Check the individual cycle type description for allowed options.

[, RAPTO, depth]

The **RAPTO** option is used to cause an additional rapid positioning operation at each point in the cycle. This option is used when performing any cycle where an additional move at high speed is desired to move the tool tip from the clearance plane to the start of the hole, for example, when performing cycle operations on points which are below the surface of the part and which can be approached at high speed, such as a counterbore.

Normally, the tool tip is positioned to the clearance plane of each point, and the cycle feedrate motion is performed from the clearance plane to the cycle depth. When the **RAPTO** option is used, an additional positioning move will be made from the clearance plane, the length of which is specified by the **RAPTO** "depth" value.

[, DWELL, (seconds)]
(REV, revolutions)

The DWELL option is used to cause a programmed wait when the machine reaches the specified depth. You can request a dwell for a number of seconds or a number of spindle revolutions. This option can be coded on the **DRILL**, **FACE**, **BORE**, **REAM** and **CSINK** cycles.

[, INVERS]

NCV accepts the **INVERS** option but ignores it.

[, ORIENT [, angle]]

NCV accepts the **ORIENT** option but ignores it.

[, DECR, value]

The **DECR** option is used to reduce the last peck amount in **DEEP** and **BRKCHP** cycles by a constant amount. These cycle types are used to drill holes where chip clearance or breakage is required.

Normally, the last peck distance specified in a **DEEP** or **BRKCHP** cycle will be repeated over and over until the full hole depth has been reached. Coding the **DECR** option will cause the final peck distance to be reduced by a specified amount each peck.

The value specifies the amount to reduce the final peck distance, at each peck. A built in minimum peck distance will prevent the **DECR** option from reducing the final peck distance to zero.

[, TIMES, count]

The **TIMES** option is only allowed with the **BRKCHP** cycle, and is used to periodically cause a full retract of the tool tip to the clearance plane. The **BRKCHP** cycle is used to drill deep holes, and performs a slight jog or delay at regular intervals to stop long chips from forming.

Every “count” pecks, the tool tip will be fully retracted to the clearance plane. On extremely deep holes, this ensures full tip clearance, and also gives the coolant a chance to reach the bottom of the hole.

DRILL Cycle

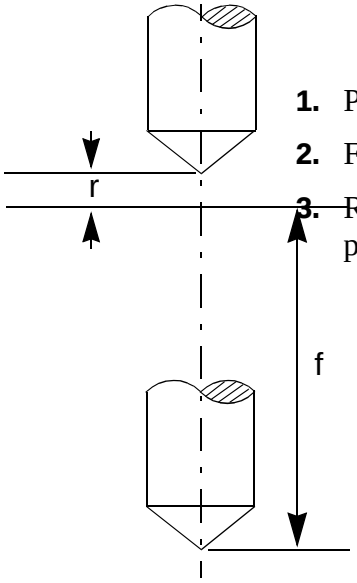
The **DRILL** cycle performs a sequence of operations equivalent to the G81 fixed cycle in ISO 1056. If a **DWELL** option is specified with **DRILL**, the **FACE** cycle is used.

The basic syntax is as follows:

CYCLE / DRILL, depth, (IPM) (IPR) (MMPM) (MMPR) , feed value [, clear] [, RAPTO, start] ...

... [, DWELL, (seconds) (REV, revolutions)]

The **DRILL** cycle causes the following motion to occur at each valid point within the cycle.



CYCLE/DRILL, f, IPM, feed value, r

1. Position at rapid to **r** above the control point.
2. Feed a distance **f+r** at feedrate inches/minute.
3. Rapid retract to a position **r** above the control point.

FACE Cycle

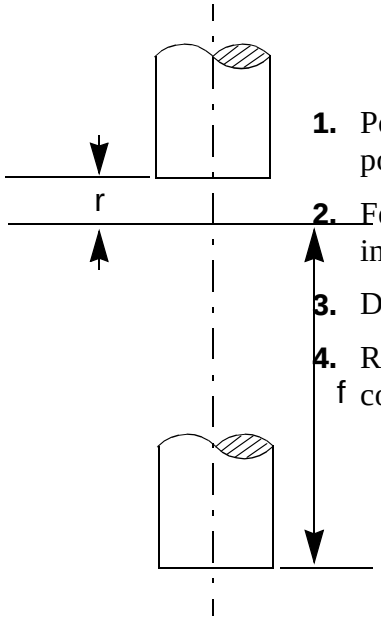
The **FACE** cycle performs a sequence of operations equivalent to the G82 fixed cycle in ISO 1056. The **DWELL** option should be specified. If not, the last **DWELL** specified, or the zero default value, will be used.

The basic syntax is as follows:

CYCLE / FACE, depth, (IPM) (IPR) (MMPM) (MMPR) , feed value [, clear] [, RAPTO, start] ...

... [, DWELL, (seconds) (REV, revolutions)]

The **FACE** cycle causes the following motions to occur at each valid point within the cycle.



CYCLE / DRILL, f, IPM, feed value, r

1. Position at rapid to **r** above the control point.
2. Feed a distance **f+r** at feedrate inches/minute.
3. Dwell for specified or default period.
4. Rapid retract to a position **r** above the control point.

TAP Cycle

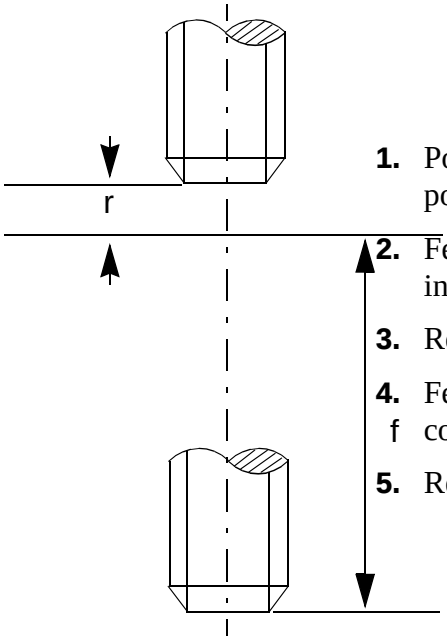
The **TAP** cycle performs a sequence of operations equivalent to the G84 fixed cycle in ISO 1056.

The basic syntax is as follows:

CYCLE / TAP, depth, (IPM) (IPR) (MMPM) (MMPR) , feed value [, clear] [, RAPTO, start] …

… [, INVERS]

The **TAP** cycle causes the following motions to occur at each valid point within the cycle.



CYCLE/TAP, f, IPM, feed value, r

1. Position at rapid to **r** above the control point.
2. Feed a distance **f+r** at feedrate inches/minute.
3. Reverse spindle direction.
4. Feed retract to a position **r** above the control point.
5. Reinstate initial spindle direction.

BORE Cycle

The **BORE** cycle performs a sequence of operations equivalent to the G86 fixed cycle in ISO 1056. If the **DWELL** option is specified, the G87 fixed cycle in ISO 1056 is used. If the **ORIENT** option is specified, the G88 fixed cycle in ISO 1056 is used. **DWELL** and **ORIENT** cannot be used together.

The basic syntax is as follows:

CYCLE / BORE, depth, (IPM) (IPR) (MMPM) (MMPR) , feed value [, clear [, jog]] [, RAPTO, start] .

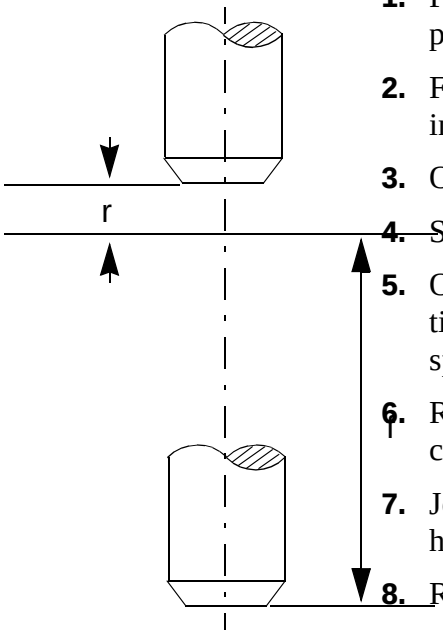
... [, ORIENT [, angle]] [, DWELL, (seconds) (REV, revolutions)]

The **jog** and **ORIENT, angle** options specify the orientation jog clearance and angle values respectively.

The **DWELL** option specifies the time to delay at full cycle depth before stopping the spindle. If this option is specified, then the **ORIENT** option cannot be specified (and vice versa).

The **BORE** cycle causes the following motions to occur at each valid point within the cycle.

CYCLE/BORE, f, IPM, feed value, r, DWELL, time



1. Position at rapid to **r** above the control point.
2. Feed a distance **f+r** at feedrate inches/minute.
3. Optionally dwell (if **DWELL** is specified).
4. Stop the spindle.
5. Optionally orient the spindle and jog tool tip away from the surface (if **ORIENT** is specified).
6. Rapid retract to a position r above the control point.
7. Jog the tool back over the center of the hole (if **ORIENT** is specified).
8. Restart the spindle.

REAM Cycle

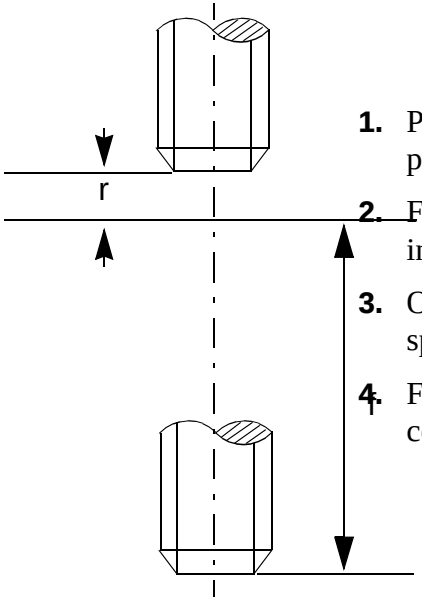
The **REAM** cycle performs a sequence of operations equivalent to the G85 fixed cycle in ISO 1056.

The basic syntax is as follows:

```
                                ( IPM       )
CYCLE / REAM, depth,            ( IPR       )
                                ( MMPM      ), feed value [, clear] [, RAPTO, start] ...
                                ( MMPR      )

... [, DWELL,                   ( seconds           )
                                ( REV, revolutions  ) ]
```

The **REAM** cycle causes the following motions to occur at each valid point within the cycle.



CYCLE/REAM, f, IPM, feed value, r

1. Position at rapid to **r** above the control point.
2. Feed a distance **f+r** at feedrate inches/minute.
3. Optionally dwell (if **DWELL** is specified).
4. Feed retract to a position **r** above the control point.

DEEP Cycle

The **DEEP** cycle performs a sequence of operations equivalent to the G83 fixed cycle in ISO 1056.

The basic syntax is as follows:

```
CYCLE / DEEP [, depth, INCR] <steps&feedrates> [, clear [, clear2]] ...
```

... , RAPTO, start] [, DECR, value] [, DWELL,(seconds)]
(REV, revolutions)

The **DEEP** cycle syntax contains three parts:

- Optional total depth specification.
- **<steps&feedrates>,** which can be one or more series of depth values and feedrate specifications.
- Standard clearance and option information.

The total depth specification **depth, INCR** is optional. It affects how the **<steps&feedrate>** information is interpreted. If the total depth is omitted, then the subsequent step data specifies the depth of each step below the control point. If the total depth is specified, the subsequent step data specifies the incremental steps of the cycle. The total depth must be coded immediately following the **DEEP** keyword, and it must be followed by the **INCR** keyword. When a depth is coded, NCV will ensure that the cycle goes to the specified depth, regardless of the total depth calculated by adding up the incremental stepping information.

The **<steps&feedrates>** parameters specify the depth of each cut and feedrate to be used. They are coded as follows:

~(, step ~[, step], (IPM) , feed value)
(IPR)
(MMPM)
(MMPR)

The tilde (~) means that the indicated items can be repeated any number of times.

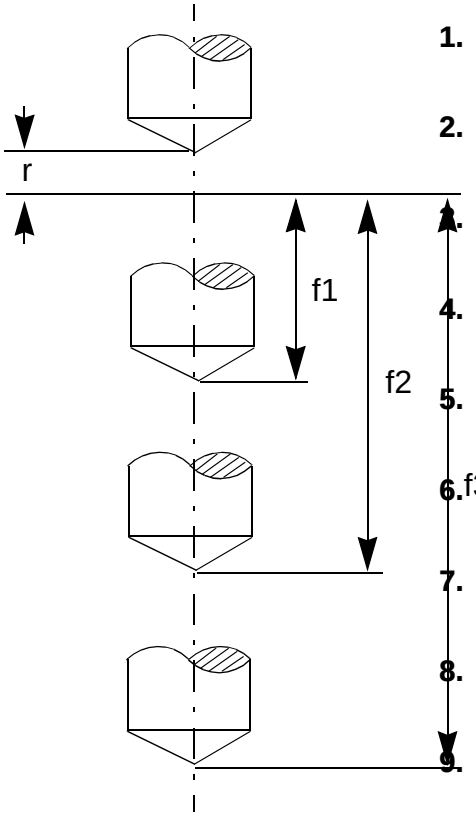
At least one step value must be coded with each increment series. It is either an incremental or absolute distance to cut before retracting from the hole to clear chips.

A feedrate type and value must be coded. This feedrate specification is used for all the stepping values that precede it. The entire group (steps and feedrate) can be repeated for as many different feedrates as required.

Once all steps have been performed, the hole is complete unless a depth has been coded. In this case, the last stepping value is repeated until the final depth is reached. If the **DECR** option is specified, then the last stepping value will be reduced by the **DECR** amount at each peck.

The clearance distances are optional. They specify the original point clearance, and the individual step clearances. If coded, they must follow the final feedrate parameter. if omitted, the defaults, both zero, will be used.

See the figure below for an example of the type of motions that are created at each valid point within a **DEEP** cycle.



CYCLE/DEEP, f1, f2, f3, IPM, feed value, r, n

1. Position at rapid to **r** above the control point.
2. Feed a distance **f1+r** below the control point at feedrate inches/minute.
3. Rapid retract to a position **r** above the control point.
4. Rapid back down a distance **f1-n** below the control point.
5. Feed a distance **f2** below the control point.
6. Rapid retract to a position **r** above the control point.
7. Rapid back down a distance **f2-n** below the control point.
8. Feed a distance **f3** below the control point.
9. Rapid retract to a position **r** above the control point.

Examples of Usage

To better illustrate the effects of different options on the **DEEP** cycle syntax, a few typical examples are provided.

Example #1:

CYCLE / DEEP, 3, INCR, .1, IPR, .02, .15, .025

This example shows the automatic repeating feature available when the total depth is specified.

The NC programmer must drill a 3-inch deep hole in steps of 0.1 throughout. The feedrate will remain constant at 0.02 inches per spindle revolution. The clearance distance will be 0.025 at each step. The initial hole clearance will be 0.15 inches.

Example #2:

CYCLE / DEEP, 5, INCR, .5, .5, .5, .5, .5, IPM, 10, .5, IPM, 8, DECR, .05

This example shows the automatic repeating feature, the specification of different feedrates at different depths, and the use of the DECR option. The clearance height defaults to zero.

The NC programmer must drill a 5-inch deep hole. A stepping distance of 0.5 inches is required until the cutter reaches a depth of 3 inches, thereafter the stepping distance should be reduced by 0.05 inches each peck. The initial feedrate is 10 inches per minute. It should decrease to 8 after a depth of 2.5 inches is reached.

Example #3:

CYCLE / DEEP, 1, 2, IPR, .02, 2.9, 3.7, 4.4, IPM, 4, 5.0, IPM, 1

This example shows a deep hole cycle that does not use the depth specification. Again, the default clearance is used.

The NC programmer must drill a 4.5 inch deep hole. The first 2 inches can be handled in steps of 1 inch at 0.02 inches per spindle revolution. The step will decrease by 0.1 thereafter at a feedrate of 4 inches per minute. The final breakthrough of 0.1 inches is done at 1 IPM by protruding the drill point 0.5 inches below the bottom surface.

BRKCHP Cycle

The **BRKCHP** cycle performs a sequence of operations equivalent to the G83 fixed cycle in ISO 1056. The **DEEP** and **BRKCHP** cycles are similar. The difference is that with **BRKCHP**, the tool does not fully retract at each step.

The basic syntax is as follows:

```
CYCLE / BRKCHP [depth, INCR] <steps&feedrates> [, clear [, clear2]] ...
        ... [, RAPTO, start] [, DECR, value] [, TIMES, value] ...

        ... [, DWELL,    ( seconds     )  ]
                         ( REV, revolutions )
```

The **BRKCHP** cycle syntax contains three parts:

- Optional total depth specification.
- **<steps&feedrates>** which can be one or more series of depth values and feedrate specifications.
- Standard clearance with option information.

The total depth specification **depth,INCR** is optional. It affects how the **<steps&feedrates>** information is interpreted. If the total depth is omitted, then the subsequent step data specifies the depth of each step below the control point. If the total depth is specified, then the subsequent step data specifies the incremental steps of the cycle. The total depth must be coded immediately following the **BRKCHP** keyword, and it must be followed by the **INCR** keyword. When a depth cycle is coded, NCV will ensure that the cycle goes to the specified depth, regardless of the total depth calculated by adding the incremental stepping information.

The **<steps&feedrates>** parameters specify the depth of each cut and the feedrate to be used. They are coded as follows:

```
                          ( IPM  )
                          ( IPR  )
~(, step ~[, step],       ( MMPM )  , feedrate)
                          ( MMPR )
```

The tilde (~) means that the indicated items can be repeated any number of times.

At least one step value must be coded with each increment series. It is either an incremental or absolute distance to cut before jogging the tool to stop long chips from forming.

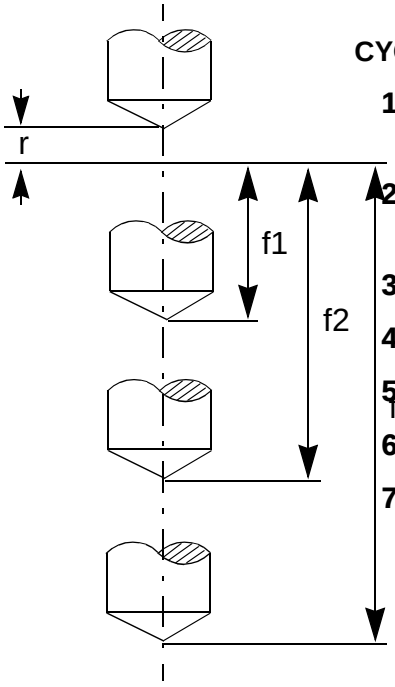
A feedrate type and value must be coded. This feedrate specification is used for all of the stepping values that precede it. The entire group (steps and feedrate) can be repeated for as many different feedrates as required.

Once all steps have been performed, the hole is complete unless a depth was coded. In this case, the last stepping value is repeated until the final depth is reached. If the **DECR** option is specified, then the last stepping value will be reduced by the **DECR** amount at each peck.

The **TIMES** option can be coded to specify how many pecks should be done between each full retract to the original clearance point. If this option is omitted, the tool will not perform any full retractions.

The clearance distances are optional. They specify the original point clearance, and the individual step clearances. If coded, they must follow the feedrate parameter. If omitted, they default to zero.

The **BRKCHP** cycle causes the motions shown in the diagram below to occur at each valid point within the cycle.



CYCLE/BRKCHP, f1, f2, f3, IPM, feedrate, r

1. Position at rapid to **r** above the control point.
2. Feed a distance **f1** below the control point at feedrate inches/minute.
3. Small retraction.
4. Feed a distance **f2** below the control point.
5. Small retraction.
6. Feed a distance **f3** below the control point.
7. Rapid retract to a position **r** above the control point.

THRU Cycle

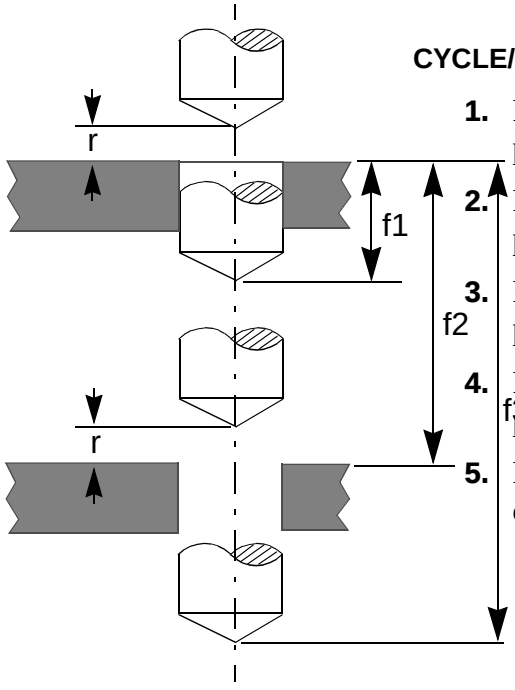
The **THRU** cycle performs a series of feedrate and rapid motions to support multiple web drilling. There is no ISO 1056 standard for this option.

CYCLE / THRU, depth ~[, start, depth] , (IPM) (IPR) (MMPM) (MMPR) , feed value

... [, clear [, clear2]] [, RAPTO, start] [, DWELL, (seconds) (REV, revolutions)]

The first “depth” value specifies the depth of the cut to drill the first web. It is followed by pairs of values which indicate the starting depth and the depth of cut for the following webs. All depth values are measured from the control point.

The clearance distances are optional. They specify the original point clearance, and the individual step clearances (secondary). If coded, it must follow the feedrate parameter. If omitted, zero defaults will be used.



CYCLE/THRU, f1, f2, f3, IPM, feed value, r

1. Position at rapid to **r** above the control point.
2. Feed a distance **f1** below the control point at feedrate inches/minute.
3. Rapid a distance **f2-r** below the control point.
4. Feed a distance **f3** below the control point.
5. Rapid retract to a position **r** above the control point.

CSINK Cycle

The **CSINK** cycle performs a sequence of operations equivalent to the **DRILL** G81 fixed cycle in ISO 1056. The **CSINK** cycle is used to chamfer holes, and provides a convenient input syntax suited to this function. If a **DWELL** option is specified, the standard **FACE** G82 fixed cycle in ISO 1056 will be used to perform the operation.

The general syntax is as follows:.

CYCLE / CSINK, odia, angle [, idia], , (IPM) (IPR) (MMPM) (MMPR) , feed value …

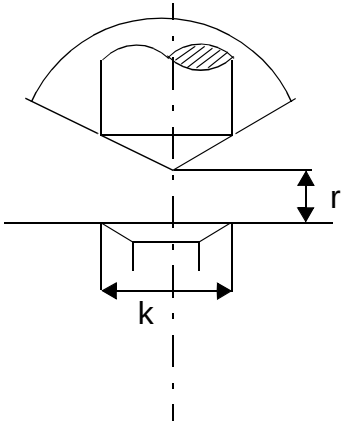
… [, clear [, clear2]] [, RAPTO, start] [, DWELL, (seconds) (REV, revolutions)]

The **odia** is the final outside diameter of the chamfered hole. For example, if a 0.06 chamfer is required on a 1 inch diameter hole, the final diameter is 1 + 0.06 x 2 = 1.12.

The **angle** (in degrees) specifies the included angle of the tool. For example, a 45 degree chamfer will require a tool having a 90 degree included angle. The angle must be specified as 90, not 45, in the **CSINK** command.

The optional **idia** specifies the original inside diameter of the hole. If this is specified, NCV will plunge the tool at a rapid rate to a calculated point clear of the original hole and then feed the remaining distance. If the inside diameter is omitted, the entire plunge motion will be performed at the specified feedrate.

The **CSINK** cycle causes the following motions to occur at each valid point within the cycle.



CYCLE/CSINK, k, l, IPM, feed value, r

1. Position at rapid to **r** above the control point.
2. Feed a distance

$$r + \frac{k}{2 \times \tan\left(\frac{1}{2}\right)}$$

Sample NCV File

```
2 PARTNO NC VERIFICATION FILE FORMAT
3 TLAXIS 0.5547 0.8325 0.0
4 LOADTL
5 CUTTER 1.0000 0.120 0.3800 0.120 0.0 0.0 2.00
8 FROM 10.0 10.0 10.0
12 SPINDL CLW 1250.00
14 FEDRAT IPM 12.50
18 RAPID
24 COOLNT FLOOD
32 GOTO 1.0 1.0 2.0
36 GOTO 3.0 3.0 4.0
38 GOTO 1.0 4.6 2.0
40 MULTAX ON
62 FROM 1.1079 -0.300 3.0009 0.000 -1.0 0.0
65 GOTO 1.1502 -0.300 2.9557 0.000 -1.0 0.0
66 PPRINT TRUE C 1.4000 0.110 0.3800 0.120 0.0 0.0 10.00
69 GOTO 4.1958 -0.300 2.9141 0.000 -1.0 0.0
76 GOTO 4.2958 -0.310 2.9141 0.000 -1.0 0.0
79 CUTTER 1.0000 0.120 0.3900 0.120 0.0 0.0 2.00
80 GOTO 4.3958 -0.320 2.9141 0.000 -1.0 0.0
83 GOTO 4.4958 -0.330 2.9141 0.000 -1.0 0.0
```

```
96 GOTO 4.5958 -0.340 2.9141 0.000 -1.0 0.0
97 LOADTL
99 CUTTER 1.2000 0.120 0.3800 0.120 0.0 0.0 2.00
103 GOTO 4.6945 -0.350 2.8415 0.000 -1.0 0.0
104 GOTO 5.0000 -0.350 2.8415 0.000 -1.0 0.0
108 COOLNT OFF
109 FINI
```

This file would be interpreted as follows:

2 PARTNO NC VERIFICATION FILE FORMAT

The part number is displayed at the top of the screen during simulation.

3 TLAXIS 0.5547 0.8325 0.0

The tool axis is changed from its default of 0.0, 0.0, 1.0.

4 LOADTL

NCV prepares to accept the next cutter as a physical tool definition. Any CUTTER statements that are not preceded by a physical tool change major word will be ignored.

5 CUTTER 1.0000 0.120 0.3800 0.120 0.0 0.0 2.00

The tool is defined using the standard APT seven parameters.

8 FROM 10.0 10.0 10.0

The tool is positioned prior to the first cut.

12 SPINDL CLW 1250.00

The spindle speed is displayed during simulation.

14 FEDRAT IPM 12.50

The feedrate and units are displayed during simulation.

18 RAPID

The next move is treated as rapid. The cutter is colored red and if any material is cut, NCV recognizes that an error has occurred.

NOTE	RAPID without an asterisk (*) applies only to the first **GOTO** following it.

24 COOLNT FLOOD

Coolant flow is displayed during simulation.

32 GOTO 1.0 1.0 2.0

The tool is swept to the specified position, because this is a rapid move, the cutter is colored red.

36 GOTO 3.0 3.0 4.0

The tool is swept to the specified position, the tool color returns to normal.

38 GOTO 1.0 4.6 2.0

The tool is swept to the specified position.

40 MULTAX ON

The I, J, and K values specified in **FROM** and **GOTO** statements will be recognized by NCV.

62 FROM 1.1079 -0.300 3.0009 0.000 -1.0 0.00

The tool is positioned prior to the next cut. Note that NCV does not sweep the tool from 1.0 4.60 2.0 to its new position. The **FROM** statement causes the tool to simply disappear and reappear at the new position.

65 GOTO 1.1502 -0.300 2.9557 0.000 -1.0 0.00

The tool is swept to the specified position.

66 PPRINT TRUE C 1.4000 0.110 0.3800 0.120 0.0 0.00 10.00

The tool is redefined using the standard APT seven parameters.

69 GOTO 4.1958 -0.300 2.9141 0.000 -1.0 0.00

The tool is positioned prior to the next cut. The preceding tool definition causes this statement to be treated like a **FROM** statement.

76 GOTO 4.2958 -0.310 2.9141 0.000 -1.0 0.00

The tool is swept to the specified position.

79 CUTTER 1.0000 0.120 0.3900 0.120 0.0 0.00 2.00

This statement is ignored. Because it is not preceded by a physical tool change statement, NCV assumes that it reflects a false cutter definition.

80 GOTO 4.3958 -0.320 2.9141 0.000 -1.0 0.00

The tool is swept to the specified position.

83 GOTO 4.4958 -0.330 2.9141 0.000 -1.0 0.00

The tool is swept to the specified position.

96 GOTO 4.5958 -0.340 2.9141 0.000 -1.0 0.00

The tool is swept to the specified position.

97 LOADTL

NCV prepares to accept the next **CUTTER** statement.

99 CUTTER 1.2000 0.120 0.3800 0.120 0.0 0.00 2.00

The tool is defined using the standard APT seven parameters.

103 GOTO 4.6945 -0.350 2.8415 0.000 -1.0 0.00

The tool is positioned prior to the next cut. The preceding tool definition causes this statement to be treated like a **FROM** statement.

104 GOTO 5.0000 -0.350 2.8415 0.000 -1.0 0.00

The tool is swept to the specified position.

108 COOLNT OFF

The coolant flow is displayed as off.

1099 FINI

Simulation stops.

Sample Control File

A control file, **tutorcl**, is supplied with the system, and is the file used with the first section of the First Cut tutorial (see “Program Components” on page 3-2). You can inspect this file as an example, using any suitable text editor.

A further example of a control file given under “The Control File Option” on page 6-3.

Sample Stock Definition in NCV File

The following example uses the **SPROF** and **SPPROF** major words to define a stock model for the simulation. The stock model is in fact that which is used in the first part of the First Cut Tutorial, defined in the **tutorcl.ncv** file that you have in your system.

As noted earlier in this chapter, **SPROF** defines the start point and thickness for the profile sweep, and **SPPROF** defines the profile sweep points.

```
0  SPROF      0.000     0.000    -0.950    2.250
0  SPPROF    16.000     0.000
0  SPPROF     5.000    -4.500
0  SPPROF    -1.000    -5.000
0  SPPROF    -4.000    -4.500
0  SPPROF    -4.000    -3.500
0  SPPROF   -13.900    -1.000
0  SPPROF   -13.900     3.000
0  SPPROF   -11.500     3.500
0  SPPROF   -10.000     5.000
0  SPPROF     0.000     7.575
0  SPPROF     8.500     7.950
0  SPPROF     9.500     8.500
0  SPPROF    12.000     6.800
0  SPPROF    16.000     3.000
```

SLA File Format

NCV accepts ASCII and binary SLA files.

The ASCII format is as follows.

The first line of the file looks like this:

```
solid name
```

where the **name** is optional.

This line is followed by descriptions of the polygons (i.e. facets), in any order. The first line of a polygon description looks like this:

```
facet normal xn yn zn
```

where the **xn yn zn** are the components of the polygon's normal vector. The vector must point outward and must be normalized.

The second line of a polygon description looks like this:

```
outer loop
```

This line is followed by the descriptions of the polygon's vertices, in either clockwise or counterclockwise order. Each vertex is described by a line that looks like this:

```
vertex x y z
```

where **x y z** are the coordinates of the vertex.

The description of each polygon ends with these two lines:

```
endloop
endfacet
```

The last polygon description is followed by this line, the last line of the file:

```
end solid
```

The following sample file represents a tetrahedron:

```
solid tetrahedron
facet normal -1 0 0
outer loop
vertex 0 0 0
vertex 0 0 2
vertex 0 2 0
endloop
endfacet
facet normal 0 -1 0
outer loop
vertex 0 0 0
vertex 2 0 0
vertex 0 0 2
endloop
endfacet
facet normal 0 0 -1
```

```
outer loop
vertex 0 0 0
vertex 2 0 0
vertex 0 2 0
endloop
endfacet
facet normal 1 1 1
outer loop
vertex 2 0 0
vertex 0 2 0
vertex 0 0 2
endloop
endfacet
end solid
```

NCV does not require the filename to have any particular extension. The file may contain any number of polygons; each polygon may contain any number of vertices.

G-Code Input

G-Codes Supported

G00: Rapid motion to the specified location

G01: Cutting motion to the specified location

G02: Clockwise arc to the specified location

G03: Counterclockwise arc to the specified location

G17: Set current plane to XY

G18: Set current plane to ZX

G19: Set current plane to YZ

G28: Go to the reference location

G40: Cancel cutter offset

G41: Start cutter offset to left of cutter path

G42: Start cutter offset to right of cutter path

G54: Set Work Coordinate System #1

G55: Set Work Coordinate System #2

G56: Set Work Coordinate System #3

G57: Set Work Coordinate System #4

G58: Set Work Coordinate System #5

G59: Set Work Coordinate System #6

G90: Use absolute cutter coordinates

G91: Use relative cutter coordinates

G92: Change the coordinate system so that specified coords apply to current position; translate all Work CS's by same amount.

Other Codes Supported

D: D-codes specify a cutter offset distance

F: F-codes specify a new feedrate

H: H-codes specify a cutter offset distance

M: M-codes are ignored

N: N-codes specify the CL-ID

S: S-codes specify spindle speed

T: T-codes cause a change to the specified cutter.

Restrictions

Circular arcs are supported, but not spiral or helical arcs.

The cutter axis is always (0 0 1).

Processing

NCV pre-processes G-code files. It runs a program called **`ncvin.gc`**. This seeks for G-code files, which must end with the extension **`.gc`** for NCV to recognize and interpret them properly.

If you run NCV for G-code files, and get error messages to the effect that the file doesn't have any **GOTO** statements, then the problem will be one of the following:

- NCV did not find the input file because it did not have the **.gc** extension.
- NCV did not find the **ncvin.gc** file, or the **.gc** file, or one of the special data files below, because they were not in the current directory.

If you get an error message complaining about APT **CUTTER** statement, which is generated by the input converter, then this means that you will have defined incorrect cutters. You can track which cutter statement is causing the problem by using the CL-ID on the APT **CUTTER** statement, which will be the line number of the original G-code statement.

Machine controllers interpret I, J, and K codes either as incremental or absolute values, based on the G90 and G91 codes. You can control the interpretation as shown in the notes on the **g.data** file below.

Special Data Files

NCV uses special data files, in addition to the input file, when reading G-codes. The formats for these are given below.

The **g.cutters** and **g.data** files must be present. If the files are not present, then NCV will complain that the input file is empty.

g.cutters

This file is to contain one cutter definition per line:
D, R, E, F, Alpha, Beta, H, NS, separated by blanks, e.g.,

```
10 2 0 0 0 0 30 24
```

where NS is an optional value specifying the number of sides on the cutter.

The file is indexed by T-codes; the first line is T01.

There must be at least one line, at most 99.

g.data

This is a three or four line file used for miscellaneous data:

line 1: Reference location X, Y, Z, separated by blanks, e.g., 0 0 100

line 2: value 1 to indicate that decimal points are used; value 0 if decimal points are not used.

line 3: 100 if units are 1/100 mm or 1/100 in., 1000 if units are 1/1000 mm or 1/1000 in.

line 4: This line is optional. It is used to specify whether you wish the machine controller to interpret I.J and K values as incremental or absolute values based on the G90 and G91 codes.
In this fourth line use:
value 1, if the interpretation of I, J, K codes depends on G90 and G91 codes.
value 0, if I, J, K are always interpreted as incremental.

d.data

This file contains cutter offset data. It is required only if D-codes are used. If the file is required, but is not present, then NCV will stop reading the input file at the point the D-code is seen.

The file contains one D-register value per line. Indexed by D-codes; first line is D01.

If a D-code is used in the input file that is out of the range of values in the **`d.data`** file, the offset retrieved is undefined. For example, if D09 were used in the input file, and the file had only five lines, then the offset retrieved is undefined.

h.data

This file contains cutter offset data. It is required only if H-codes are used. If the file is required, but is not present, then NCV will stop reading the input file at the point the H-code is seen.

The file contains one H-register value per line. Indexed by H-codes; first line is H01.

As for D-codes, if an H-code is used in the input file that is out of the range of values in the **h.data** file, the offset retrieved is undefined.

g.wcs

This file is not required unless the input uses Work Coordinate System offsets.

The file contains up to 6 lines. Each line contains the X, Y, and Z offsets of the corresponding Work Coordinate System, separated by blanks.

line 1: Work Coordinate system #1 (G54)

line 2: Work Coordinate system #2 (G55)

line 3: Work Coordinate system #3 (G56)

line 4: Work Coordinate system #4 (G57)

line 5: Work Coordinate system #5 (G58)

line 6: Work Coordinate system #6 (G59)

If the **g.wcs** file is required, but either does not exist or is accessed using an out-of-range index, then the coordinates default to 0,0,0.

CATIA File Input

NCV accepts CATIA files. The following points should be observed:

- When running the CATUTIL utility that creates the APT file, you must set circular interpolation to off.
- You must give the APT file an extension of **.catia**, although this is customizable. The CATIA input converter, ncvin.catia, is shipped with the product. If you want to use another filename extension for your APT files, this file should be renamed to that extension, e.g., if you suffix your files with **.cat** then rename or copy the converter to ncvin.cat.

- The CATIA input converter ignores the following APT statements: **INTOL**, **OUTTOL**, **LINTOL**, **ROTHED**, **SEQNO**, **PREFUN**, **INSERT**, **ORIGIN**.

Tool Holders

Tool holders can be modeled. Collisions of the tool holder against the stock or fixtures are detected and reported.

You can also specify a flute length for each cutter (the length of the portion usable for cutting). Attempts to cut with the shaft (the portion of the cutter above the flute length) are detected and reported.

Tool holders are solids of revolution. They are described in a library, whose format is described below. The library file is named ncvholder.lib, but this can be changed in the application-defaults file **`Ncver`**.

The tool holder to be used for a particular cutter is specified using the **'PPRINT HOLDER <name>'** statement. The **PPRINT HOLDER** statement applies to all following **CUTTER** statements until the next **PPRINT HOLDER**. If no name is specified, no holder is used for the affected cutters.

For each holder in the library, a flute length can be specified, even if there is no holder geometry. This flute length is then applied to the cutters using this holder. If a flute length has been specified for a cutter, the cutter is reduced to just its flute length and the shaft portion of the cutter is replaced with a shaft cylinder (or cone, in the case of tapered cutters).

There is a switch, ❑ Ignore holder and shaft, in the **Auto** menu, which allows you to ignore holders and shafts even if they are specified. This is useful because displaying the holders and checking for collisions slows down the simulation, probably by an order of magnitude over simulating the cutter alone.

If the check button is checked, but flute lengths have been specified, the cutters are still reduced to just their flute length. That is, checking the button does not make NCV act exactly as in previous releases. To do that, you would have to remove the **ncvholder.lib** file (or rename it or remove read permission from it).

If a default cutter is used, i.e., the input file contains **GOTO** statements before the first **CUTTER** statement, there is no way to specify a holder (or flute length) for that cutter.

The G-code converter handles holder names. In the **g.cutters** file, the **NSIDES** parameter can be followed by a holder name. If the holder name is specified, the **NSIDES** parameter must be specified. The **NSIDES** parameter can be zero, whether or not a holder name is specified; in this case the default value for **NSIDES** is used. The holder name refers to the holders in **ncvholder.lib**, just as the **PPRINT HOLDER** statement does.

Format of ncvholder.lib File

The format of the **ncvholder.lib** file is as follows.

- The file consists of a series of cutter descriptions, each of which looks like this:

```
name [FLUTE length]
     x y
     x y
       :
       :
```

- The name lines are left-justified; the coordinate lines have leading white space (blanks and/or tabs). Blank lines and comment lines are ignored; comment lines are those beginning with an exclamation-mark character.
- Names cannot contain blanks, tabs, slashes, or commas; case is significant in names. The word **FLUTE** can be upper- or lower-case.

- The coordinates describe the profile of the holder, which is a series of lines revolved about the Y axis. The first and last X coordinates must be zero, i.e., the profile can not have a hole up the middle like a doughnut.
- Moreover, the Y coordinates must be non-decreasing, i.e., it is not possible to model a hole in the end for inserting the cutter. However, the holder and the cutter can interpenetrate, so this is not a problem. (The reason for these restrictions, by the way, is to allow the holder to be decomposed into convex solids, which is required by NCV's subtraction algorithm.)
- Tool holder profiles can contain arc lines. The same rules govern them as form-cutter arcs; see "Arc lines are of the form:" on page 10-129.
- When the holder is used in the simulation, its origin point (0,0) is moved to the current CL point. Then it is oriented so that its axis lines up with the cutter axis.
- Note that if a holder is moved up or down, all its Y coordinates change, so it becomes essentially a new holder.

Sample ncvholder.lib File

A sample **`ncvholder.lib`** file is included with the product, containing two sample holders, named **`SampleHolder1`** and **`SampleHolder2`**. If you wish to practice adding a holder statement, you can use the tutorcl.ncv file that comes with the product:

- Copy tutorcl.ncv to, say, **`keep.ncv`**
- Edit **`keep.ncv`** by adding a new first line:

```
PPRINT HOLDER SampleHolder2
```

- Run ncver using the input file **`keep.ncv`**.

Form Cutters

Form cutters can be modeled.

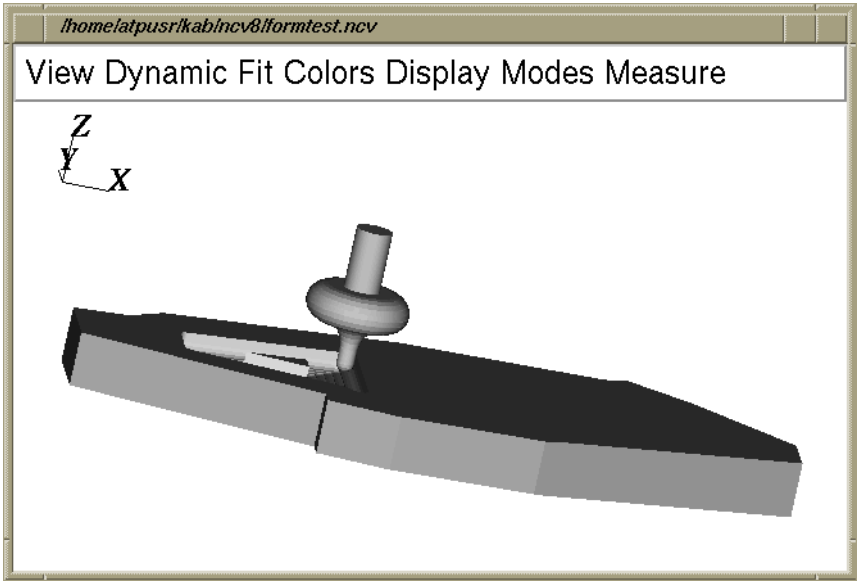


Figure 10-55 Modeling form cutters

First Cut defines these as solids of revolution whose profiles consist of lines and arcs. A form cutter is used in an NCV input file with a statement of the form:

PPRINT/FORM name

where **name** is the name of the cutter.

Cutters are defined in the file **`ncvcutter.lib`**. It consists of a series of cutter definitions. Each definition consists of a name line followed by a series of coordinate lines. A name line consists of the cutter name, with no leading white space.

Coordinate lines begin with white space (a blank or a tab); they are defined below. Blank lines and comment lines (beginning with "!") are ignored. Each coordinate line defines either a point or an arc.

Two consecutive point lines implicitly define the line segment between them. Two point lines with an arc line between them define the circular arc between them. (Each arc line must be preceded and followed by point lines.)

Point lines are of the form:

x y

Arc lines are of the form:

arc xc yc r

where **(xc,yc)** is the center of the arc and r is its radius.

Arcs are always taken to be less than 180 degrees. To create an arc of exactly 180 degrees, it should be split into two arcs.

The points of the profile are specified in bottom-to-top order. Their Y coordinates must be non-decreasing.

The (0,0) point of the profile's coordinate system is mapped to the CL point during simulation, and the Y axis is mapped to the tool axis.

The first and last points of the profile must have X coordinate 0; in general the first point will be (0,0). Form cutters are not affected by the Cutter Limits dialog.

First Cut Tutorial

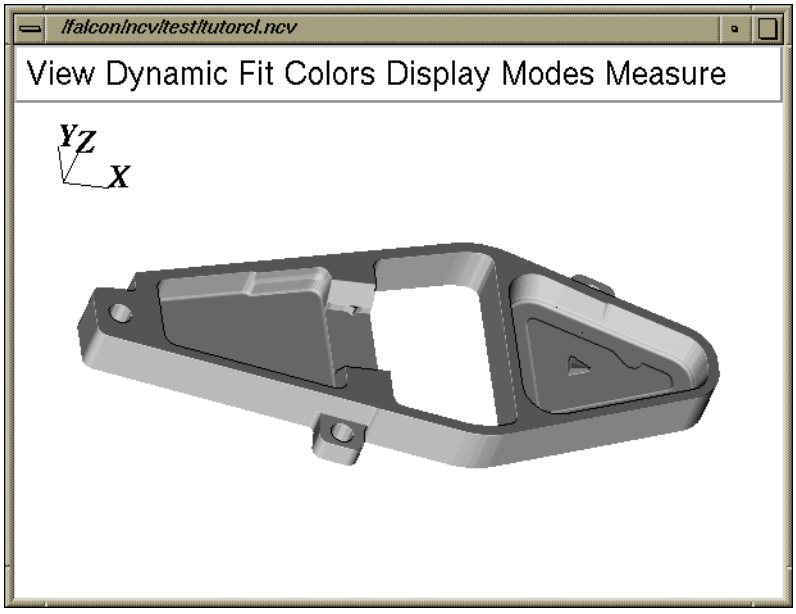


Figure 10-56 First Cut Tutorial

This section demonstrates basic First Cut product functions by leading you through a simulation session using tutorial files provided with the system. The tutorial should take approximately two hours to complete and includes the following:

- Brief description of the First Cut Program components.
- Simulation Session 1, which includes an introduction to the user interface, reading input files, practicing with various functions, carrying out an actual simulation, and recording and playing back the session.
- Session 2, in which you run another simulation and compare the results with an as-designed part model.

- Description of other production facilities.

NOTE This tutorial is available on-line. You can display it by selecting the Tutorial button on the Help menu.

Program Components

Figure 10-57 shows the organization of NCV.

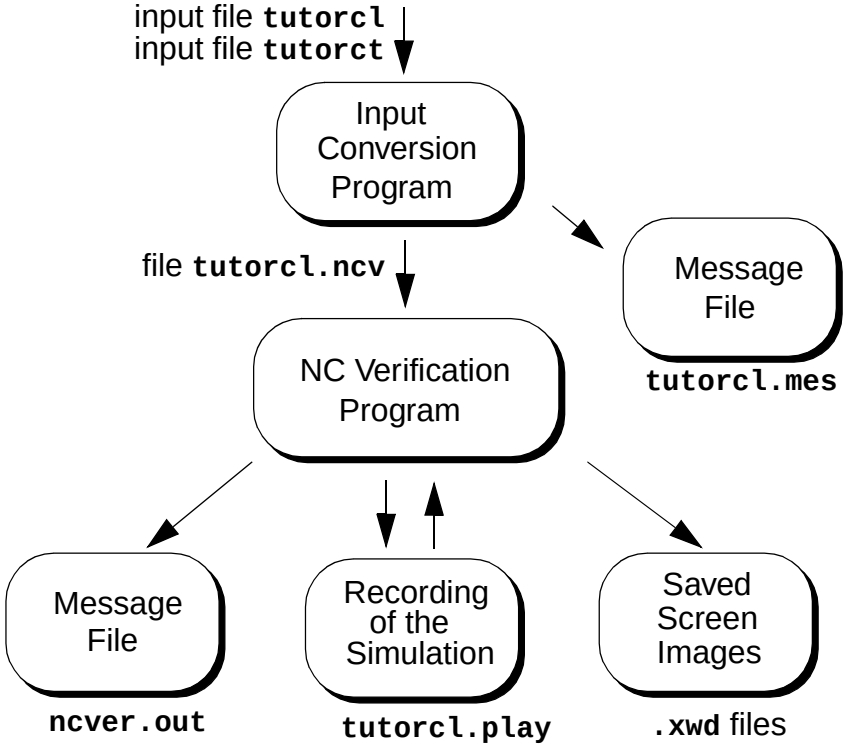


Figure 10-57 NCV organization

You will practice using the components above during this tutorial. In summary, they comprise:

- First, the CL-FILE Conversion Program, **cltoncv**. This takes two input files:

  tutorcl, which contains the APT-CL, and

  tutorct, which contains control statements.

It produces the file **tutorcl.ncv**, for input to the NC Verification Program, and the file **tutorcl.mes**, which contains messages generated during the conversion.

- Second, there is the NC Verification Program itself, which provides you with the graphical simulation of the machining of the part. This has the outputs shown:

  An Error File, which contains a text description of each error detected during the machining. For example, it could contain a statement that it detected a rapid movement into the stock, and would list the CL-IDs of the commands that caused the movement.

  A recording of the simulation, which permits the replaying of the simulation, either from within the current session, or at a later time.

  Saved Screen Images. These are snapshots of the screen, taken when, for example, an error is detected; or they may be snapshots that you have taken manually during the session.

Full details of the above system components are given in this manual, and you will be practicing many of them during this tutorial.

Tutorial Prerequisites

Before running the tutorial, please ensure the following:

- You are logged on to the workstation. See your workstation Owner's Manual for logon instructions.
- If necessary, change directory to the directory which contains the NCV software.
- Your CL file (**tutorcl**) and control file (**tutorct**) must be converted to First Cut format before you can begin the simulation. To perform the conversion, make sure the two files are in the current directory, then enter the command:

```
cltoncv tutorcl tutorct <RETURN>
```

Your screen will look something like this:

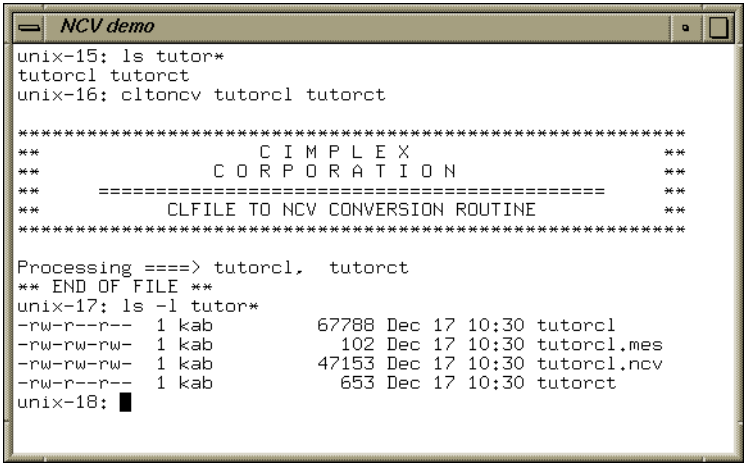

NCV demo
unix-15: ls tutor*
tutorcl tutorct
unix-16: cltoncv tutorcl tutorct
****
** C I M P L E X **
** C O R P O R A T I O N **
** ========== **
** CLFILE TO NCV CONVERSION ROUTINE **
****
Processing ====> tutorcl, tutorct
** END OF FILE **
unix-17: ls -l tutor*
-rw-r--r-- 1 kab 67788 Dec 17 10:30 tutorcl
-rw-rw-rw- 1 kab 102 Dec 17 10:30 tutorcl.mes
-rw-rw-rw- 1 kab 47153 Dec 17 10:30 tutorcl.ncv
-rw-r--r-- 1 kab 653 Dec 17 10:30 tutorct
unix-18:

Figure 10-58

The illustration shows the files in the directory before running the command, i.e., the two input files, **`tutorcl`** and **`tutorct`**. The **`cltoncv`** command is on the next line, followed by the banner displayed by the program while it is running. After this, all the files whose names command with “tutor” have been listed, and you will see that in addition to the original input files there are now the **`.ncv`** file, for input to the NCV program, and the **`.mes`** file which contains messages generated during the conversion.

See “Converting a CL File (cltoncv)” on page -66 for more info on the CL file converter.

Simulation Session - Part One

Reading the NC File

You will see the Read NCV File panel, which is the file selection window for NCV:

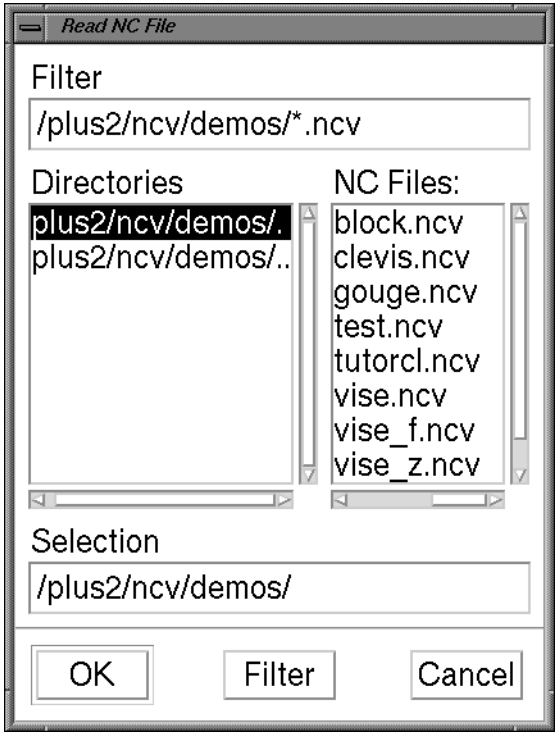


Figure 10-59 The Read NCV File panel

This window shows you the files with the suffix **.ncv** in your current directory. The name of the directory is highlighted.

Above the Directories list is the Filter field. This works using any combination you wish of directory and file names, and wildcards. A **wildcard** is an asterisk (*) and is used to denote any string of characters when you are searching for a name; a question mark (?) may be used as a wildcard for a single character. In the example, you can see that the filter has been set to the highlighted directory—you could have keyed this in, or selected it from the file list using the left

mouse button. The end of the filter has been set to **`*.ncv`**, which means that you want to see all files in the selected directory that have a suffix of **`.ncv`**.

In accordance with the filter, the NC Files listed in their box are all those with the given suffix. Note the scroll bars that are to the right and below the Directories list and NC files. If you put your cursor on the slider bar (or marker), you can scroll your way up and down the lists, or from left to right of any name.

Select the file that you previously created, **`tutorcl.ncv`**, by selecting it with the mouse. The name will be transferred to the Selection box. Now you can select *OK*, to read in the file. Instead of selecting *OK*, you can also double-click on the file name to read in the file.

The Read NC File dialog is dismissed, and you will see the *Metal Removal Window*.

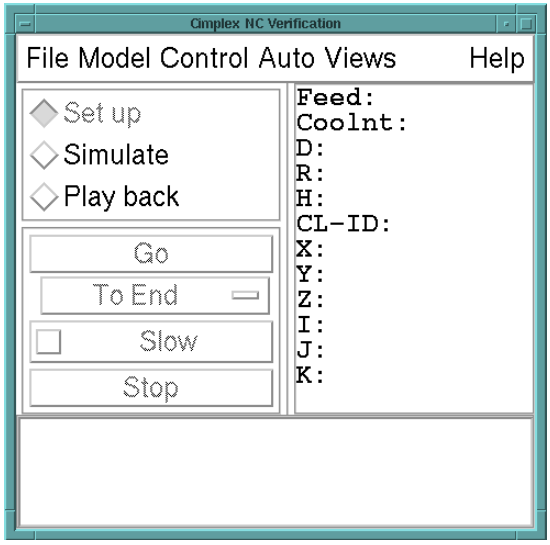


Figure 10-60 The *Metal Removal Window*

In parallel, First Cut will be creating a *Geometry Window*:

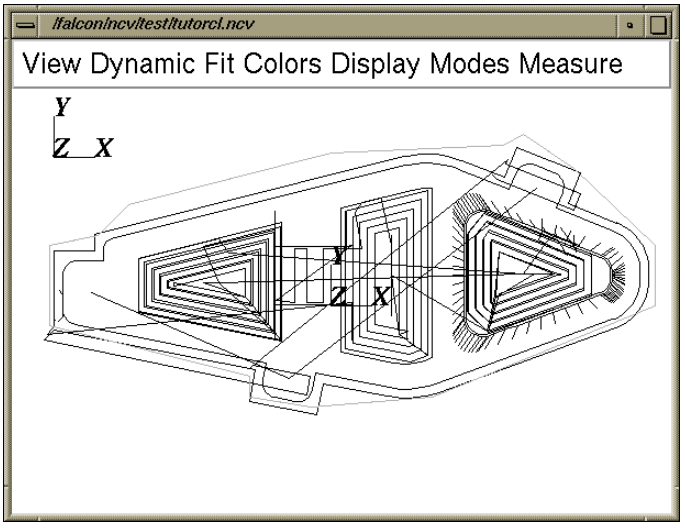


Figure 10-61 A *Geometry Window*

Metal Removal Window

This is the *Metal Removal Window*:

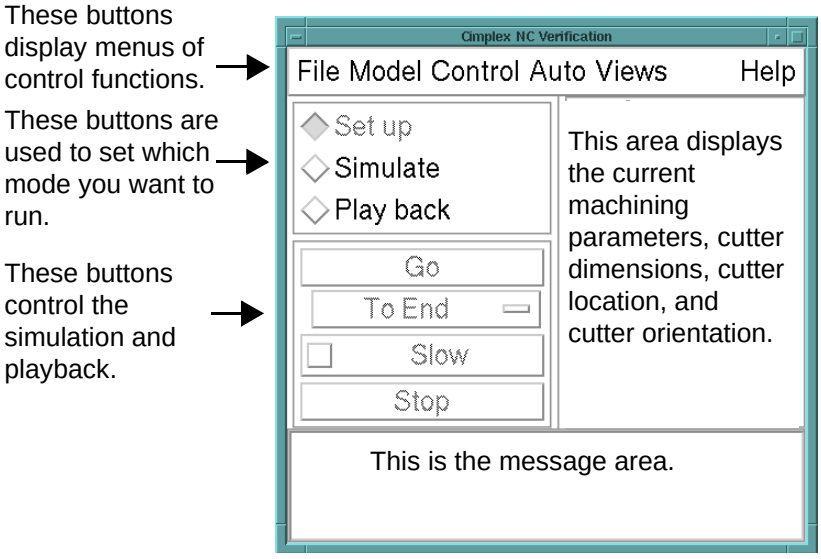

These buttons display menus of control functions.
These buttons are used to set which mode you want to run.
These buttons control the simulation and playback.
Cimplex NC Verification
File Model Control Auto Views Help
Set up
Simulate
Play back
Go
To End
Slow
Stop
This area displays the current machining parameters, cutter dimensions, cutter location, and cutter orientation.
This is the message area.

Figure 10-62 The *Metal Removal Window*

In this illustration, note that the ◆ Set up button is toggled. This is the mode you are in at the moment. We will begin with the setup procedures.

Geometry Window

Your *Geometry Window* shows the wireframe stock model and the tool paths for the tutorial part. The name of the part is at the top of the frame bordering the window:

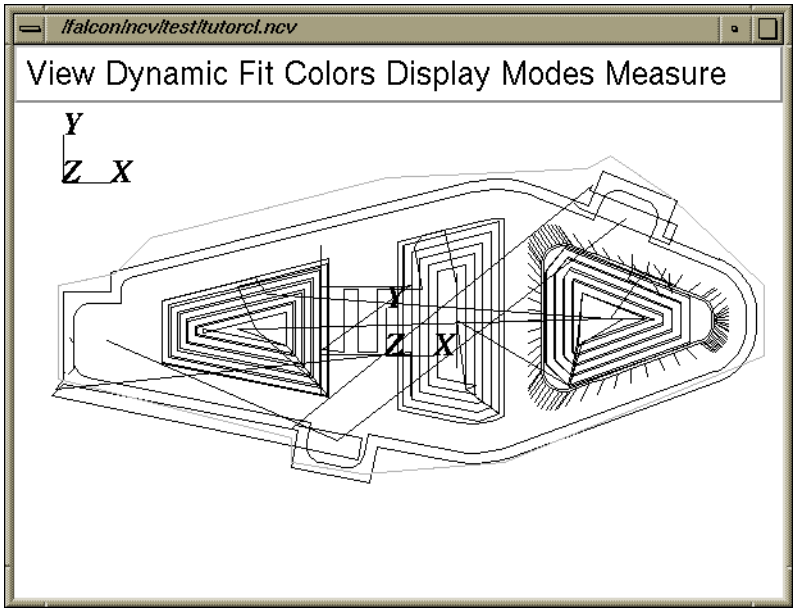


Figure 10-63 A *Geometry Window*

Display of Coordinate System Axes

Note that the axes are displayed at the origin and at the top left hand corner of the view. This is because the display of the coordinate system axes is switched on. Select the **Display** button from the top of the *Geometry Window*. The **Display** menu is displayed. If you select the ❑ Show axes switch, you can turn the axes display on and off.

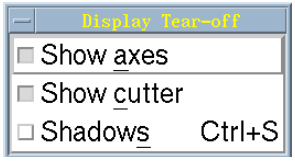


Figure 10-64 The **Display** menu

Cutter Display Button

The ❑ Show cutter button is used to turn the display of the cutter on and off. Leave it checked, i.e., switched on, for now.

Ignore the ❑ Shadows button for the time being; you will use that later.

View Selection

The default view displayed is the front view. In your *Geometry Window*, select the **View** button, which gives you the following menu showing all the views you can select directly.

Figure 10-65 The **View** menu

Note that two of the buttons have keys identified alongside them. These are the "keyboard shortcuts" you could use for using the facility instead of invoking the menu and making a selection. For example, if you wish to get an isometric view quickly using the keyboard, you would simply hold down the <ALT> key while pressing the <I> key.

For now, use the mouse to select the button labeled *Iso*. The model is now shown in isometric view. You can flick through the other buttons to see the various views, but to resume the tutorial, leave the model in the isometric view.

Creating Multiple Views

While we will run the tutorial with just the one view, you can in fact have several views running simultaneously. To bring up another view, simply select **Views** from the top of your *Metal Removal Window*, which gives you a one-button menu:

Figure 10-66 Creating views

Select the single button, which will give you another view. Then, take the view down by selecting **View** in the *Geometry Window*, and then *Close*.

Changing the View

Returning to your isometric view, you can now adjust it to suit your own purpose. From the top of your *Geometry Window*, select the **Dynamic** button. The following menu is displayed:

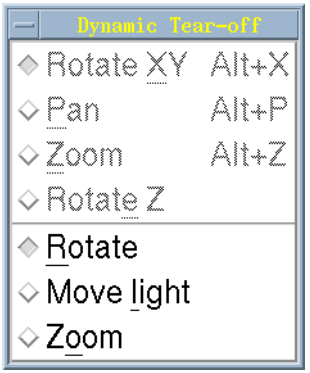


Figure 10-67 The **Dynamic** menu

Note that the ◆ Rotate XY button is toggled. This means that you can rotate the part in the X and Y axes. Move your cursor into the view of the part, and, using the middle mouse button, experiment with moving the part.

Next, select the **Dynamic** button again, and this time toggle ◆ Rotate Z in the menu. You can now go back down to the view of the part and rotate it about the line of sight, using the middle mouse button.

Also from the **Dynamic** button, you can select:

◆ Pan — to move the part around the screen. If you press your center mouse button and move your cursor in the display, then the part will follow the cursor.

◆ Zoom — to zoom in or out from the part. Again, press your middle mouse button, and as you move upward the part will be magnified, and will grow smaller as you move downward. Do this and leave a scaled down model of the part somewhere in the window.

Now select the **Fit** button from the top of the *Geometry Window*, which displays this menu:

Figure 10-68 The **Fit** menu

First, select *Center*, and you will see that this moves the origin of your part to the center of the window without changing its size. Now select *Fit*, and your part will be resized to take up the full window.

It is worth noting here that the zoom function above is for setting up the simulation. During the simulation itself, there is another zoom function available, to enable you to zoom in on any area of the part of interest; we will see this later. For now we will start the first simulation.

Commence the Simulation

Use the mouse to select the button labeled **Simulate** from the *Metal Removal Window*. A shaded image of the stock is now displayed:

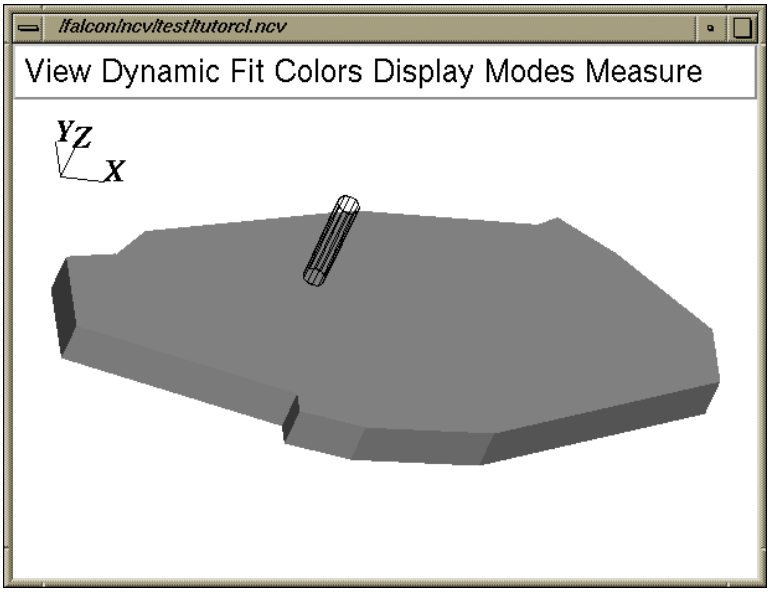


Figure 10-69 Simulating the stock

Automatic Action Control

Select the button labeled **Auto** from the top of your *Metal Removal Window* to display the following menu:

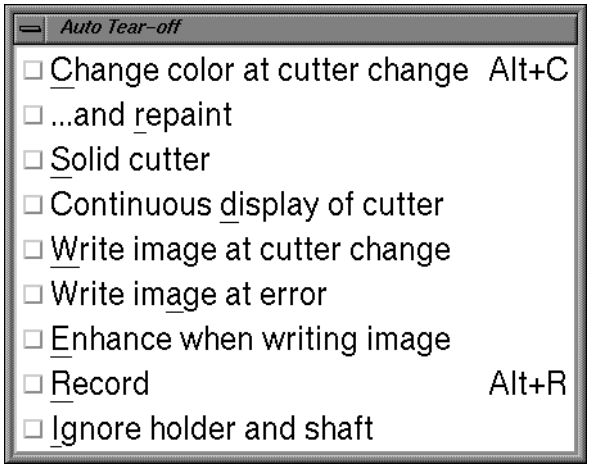


Figure 10-70 The **Auto** menu

This menu controls actions that First Cut carries out automatically. For example, writing a snapshot image of the screen every time an error is detected, so that you can view the image separately later; or displaying the cutter as a solid instead of in wireframe.

For now, just switch on ❑ Change color at cutter change. This option automatically changes the color of the material removed at each cutter change.

Setting Color Options

Now go to your *Geometry Window* and select the **Colors** button. This will give you the following list of options:

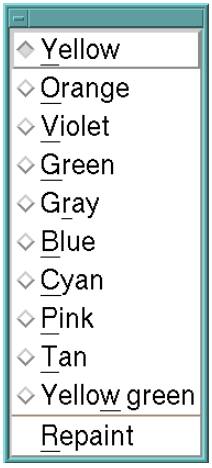


Figure 10-71 The **Colors** menu

You will see that ◆ Yellow is toggled, so this will be the color of the first cuts made in the part, and at each cutter change the colors will cycle through the list. If you want to commence with a different color, simply toggle that one instead.

If you want just one color for the cuts, you would toggle it, then go back to the **Auto** menu and turn off the ❑ Change color at cutter change option.

Setting up Recording

Select again the **Auto** button on your *Metal Removal Window*. Select ❑ Record to switch on the simulation playback log. This will allow you to re-run the simulation in a fast replay mode after you have finished.

There will be a delay of a few seconds while the playback file is initialized.

Setting Automatic Check Points

In your *Metal Removal Window*, in the simulation control area, is a button labeled *To End.* Select this, and you will see the following pop-up menu:

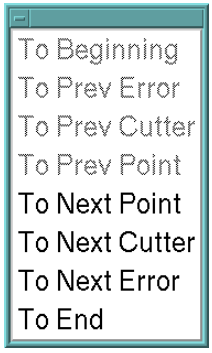


Figure 10-72 *To End* choices

The highlighted buttons give you the option of how far you want the simulation to run before it halts automatically. *Next Point* takes you to the next CL point; *Next Cutter* takes you to the next cutter change, *Next Error* takes you to the next error. For the moment, select *To End*, to run completely through the simulation in one session (we will look at the unhighlighted buttons later; these are used in Playback mode.)

Next, select *Go* to begin the simulation. Note that the *Go* button changes to *Running* while the simulation is active.

Rapid Motions

The cutter color turns red to indicate RAPID motions. Notice that when a RAPID motion cuts the part, the cut is displayed in red and an error message is given.

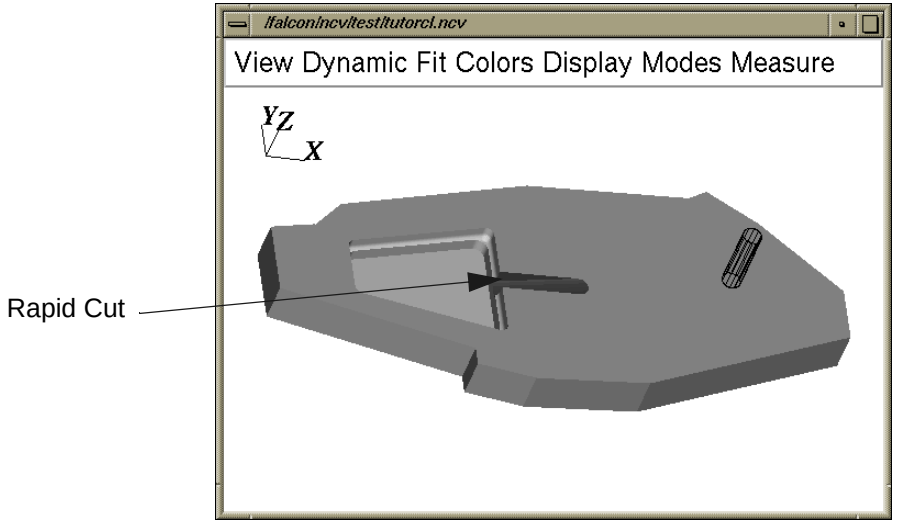


Figure 10-73 RAPID motions

Stopping or Slowing Down the Simulation

During the simulation, you can select *Stop*, to pause the program, or *Slow*, which causes the program to operate at one CL point per second.

Viewing in Translucent Mode

You can make the stock model translucent during or after the simulation. Select the **Modes** menu from your *Geometry Window* then switch on ❑ Translucent. This enables you to see into the stock as it is being cut.

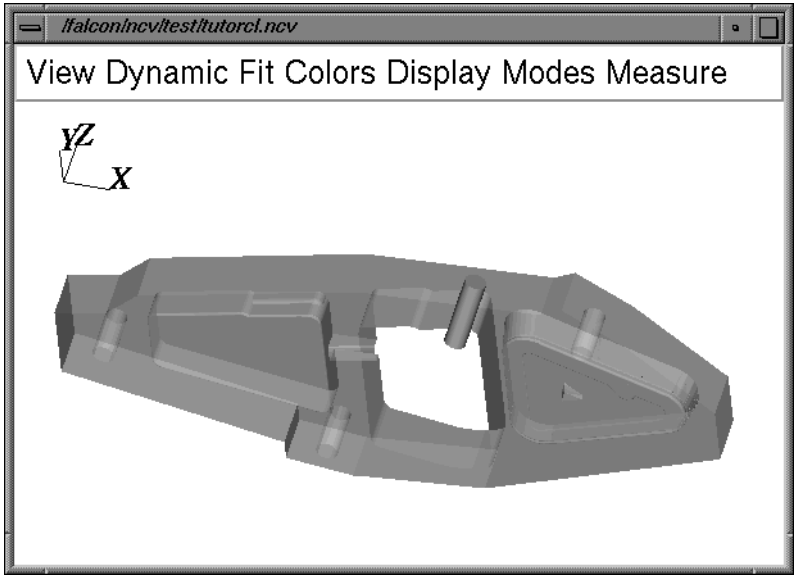


Figure 10-74 Translucent mode

Error Messages

Note that during the session, whenever an error is detected, a message is displayed. This message is, of course, also written to the Error File we mentioned previously; and, if you switched on ❑ Write image at error in the **Auto** menu, a snapshot of the screen at that point would also be written.

End of Simulation

The message "End of simulation file" is displayed in the message area when the simulation is completed.

Chip Removal

Now you can remove the unwanted material in the display of the part.

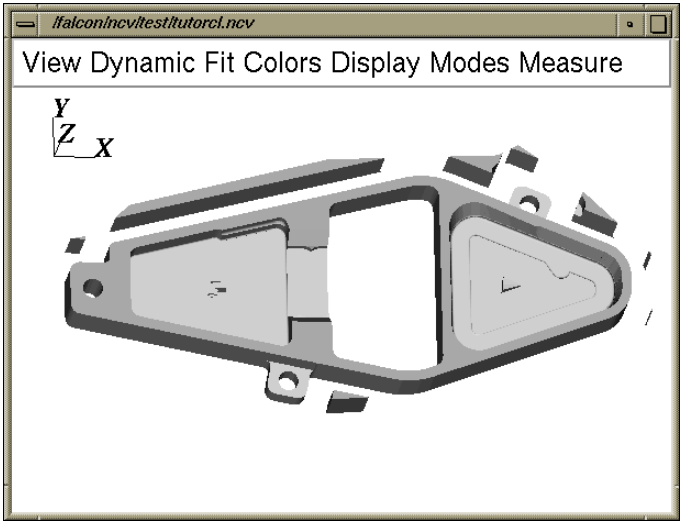


Figure 10-75 Chip removal

First, using the left mouse button, click your cursor on the body of the part to select it, and then select **Measure** from the top of your *Geometry Window*. The following menu is displayed:

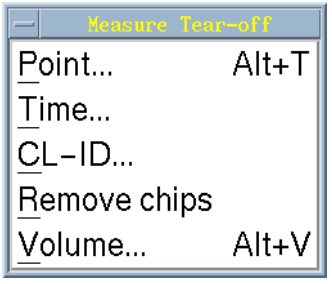


Figure 10-76 The **Measure** menu

Select *Remove chips*. This will cause all loose material to be removed.

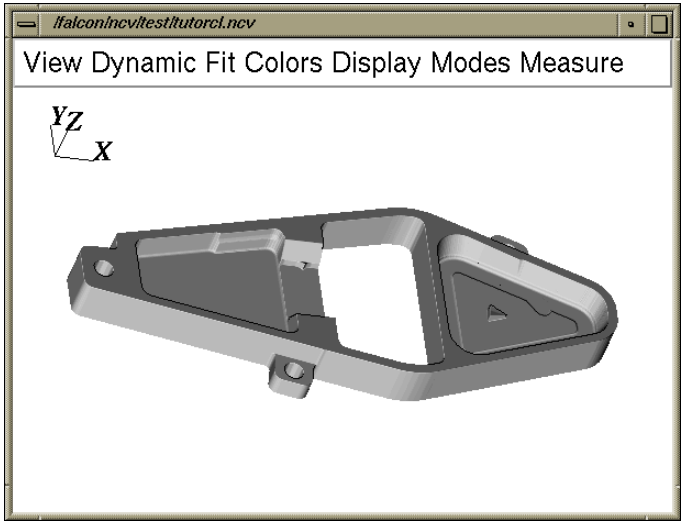


Figure 10-77 Chip removal

Simulation Evaluation

From the **Measure** button, access the **Measure** menu again, and check out the other items:

Point Measurements

Point... displays the following dialog window:

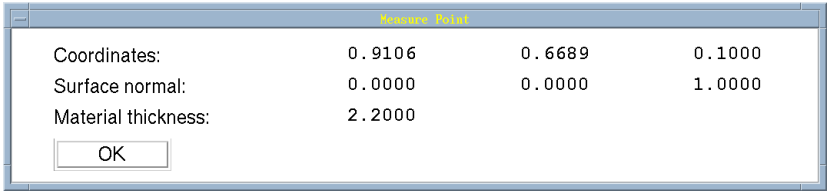


Figure 10-78 *Point...* dialog window

To measure, select any point on the part surface, using your left mouse button.

The dialog displays precise, rather than approximate, coordinates of the point being measured. It also displays the precise surface normal (the direction perpendicular to the surface) and the precise material thickness.

Display of Machining Times

Selecting *Time...* displays the Measure Time panel.

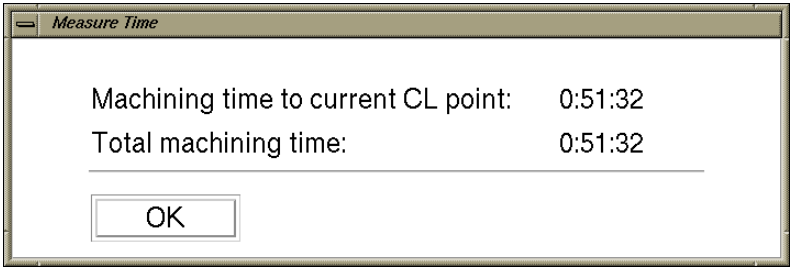


Figure 10-79 The Measure Time panel

This displays the Machining time to the current CL point, and also the total calculated machining time. The illustration shows the display at the end of a simulation run. Obviously, since you have just run your simulation, the times in your display are now equal. During a simulation, you get the time to the current point.

The machining times displayed are established as follows:

The display is of the machining time from the beginning of the current file to the current CL point and the total machining time calculated for the file. If simulation has not been started, the current time is zero; if simulation has completed, the current time equals the total time.

The calculations assume that all feedrates in the input file are expressed in the same units, i.e., inches or millimeters, and that the coordinate system is in the same units.

The times include only cutting motions, i.e., they do not take into account RAPID motions, tool changes, or manual operations. Similarly, a **FROM** statement, which causes the cutter to jump to a new location, is assumed to take no time.

Display of CL Data

Select *CL-ID* from the **Measure** menu. The Determine CL-ID panel is displayed.

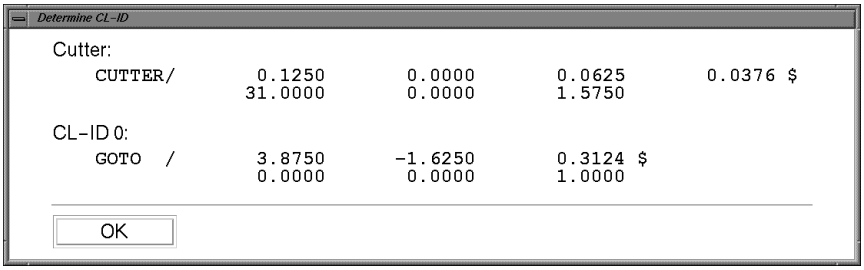


Figure 10-80 The Determine CL-ID panel

If you select (click) at any point on your part model, then details for that cut on the surface will be displayed:

- The cutter description is displayed as a **CUTTER** statement for APT cutters and as a **PPRINT/FORM** statement for form cutters.
- The motion is displayed as a **GOTO** statement showing the point's X, Y, Z, and I, J, K coordinates.

Volume Calculations

You can measure the volume of the stock at any time during the simulation. To do this, select *Volume...* from the **Measure** menu. The Measure Volume panel is displayed.

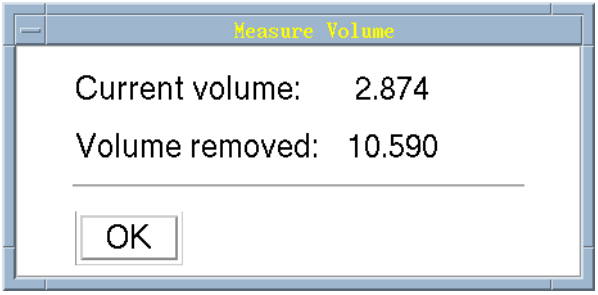


Figure 10-81 The Measure Volume panel

Clicking the left mouse button on the stock gives you the above data. Note that you will get only the volume in the view, and so, for example, if you were zoomed in and some part of the stock was not in sight, then you would not get an accurate reading.

Repaint

Now select the **Colors** button again, at the top of the *Geometry Window*, and from the **Colors** menu select *Repaint*. You will see that this repaints the image—it paints all cuts in the current color, and changes this cut color each time you repaint.

Sectioning the Part

Select the **Modes** button from the top of your *Geometry Window*, which gives this menu:

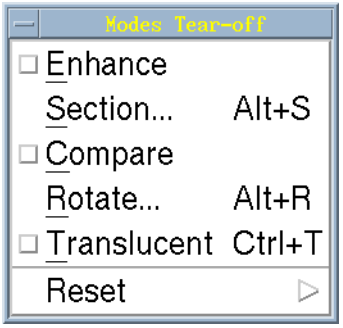


Figure 10-82 The **Modes** menu

Next, select *Section*, which displays the Section panel:

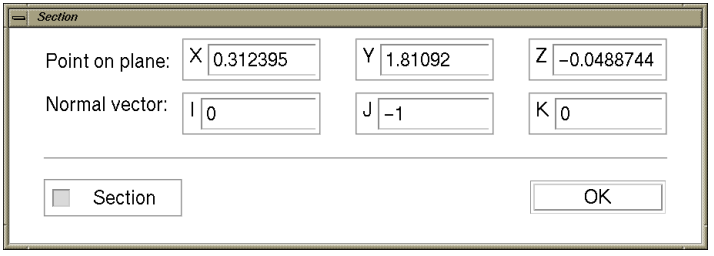


Figure 10-83 The Section panel

You can identify the section plane by typing in the coordinates of a point on the plane and the plane vector; you can also identify the coordinates by clicking at the desired point on the model. *Reset*, on the **Modes** menu, restores the image of the complete part.

Rotating the View of the Part

There are two shaded rotation facilities in First Cut, which can be used during and after the simulation, which allow you to swivel the part model about its vertical or horizontal axis, in order to see the part from different angles:

- The first uses the Rotate Shaded Image panel, in which you state the absolute number of degrees you wish the part to be rotated.
- The second is invoked using the middle mouse button. How to do this is described in "Dynamic functions during simulation" on page 2-8.

For now, check out the Rotate Dialog, as follows:

Rotate Dialog

Select the **Modes** button in the *Geometry Window*, and then select *Rotate*. This displays the dialog:

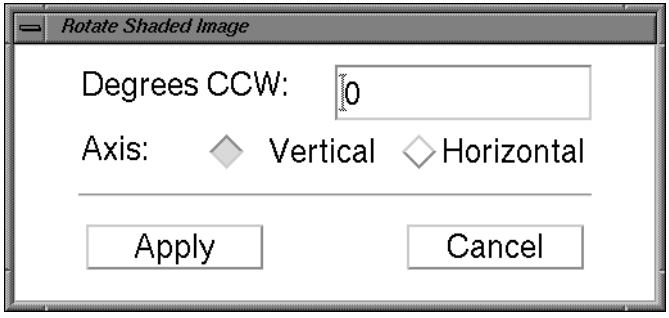


Figure 10-84 The Rotate Shaded Image panel

To rotate the part:

Enter the number of degrees, negative if you wish, that you want the part to be rotated. For vertical rotation, a positive angle causes the front of the part to move to the right, and a negative angle causes it to move to the left. For horizontal rotation, a positive angle rolls the front downwards, and a negative rolls the front up.

Select *Apply*.

Select *Cancel*, or select *Reset* from the **Modes** menu, to restore the original image.

Flipping the View of the Part

Now select again the **View** button from in the *Geometry Window*, and select *Flip*. This gives you a view of the part flipped through 180 degrees. Selecting *Flip* again restores the original view.

We will look at some of the other Modes buttons later.

Zooming in on the Part

This function is described under “Mouse buttons” on page 2-7. Try it, as follows:

- Select an area of the *Geometry Window* to be enlarged by holding down your right mouse button and dragging the cursor diagonally across the area to be zoomed.
- Release the button and the area will be redrawn to the size of the window.

■ To get the view back as it was, select the **Modes** menu in the *Geometry Window*, and select *Reset* and *Reset zoom*:

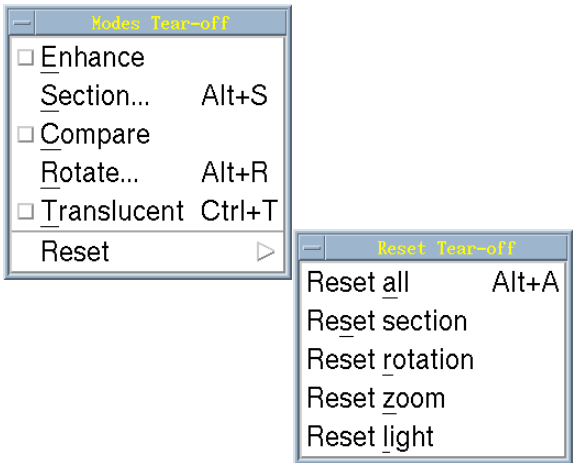


Figure 10-85 The **Modes** menu

Light Source and Shadows

You can move the light source in your view of the model by toggling the ◆ Move light button in the **Dynamic** menu.

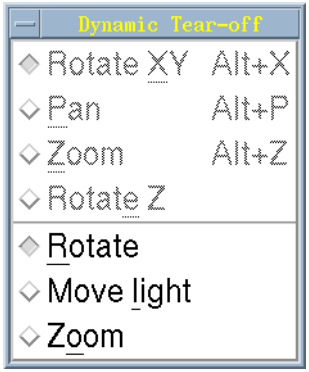


Figure 10-86 The **Dynamic** menu

Either click the middle mouse button or drag it to place the light source. Clicking (or letting up) the button in the center of the window places the light source at the eyepoint, where it is normally. Clicking or letting up at the edges of the viewport places the light

source in that direction, at right angles to the line of sight. Clicking or letting up in intermediate locations places the light source at intermediate directions.

You can also have the model with shadows by switching on ❑ Shadows in the **Display** menu:

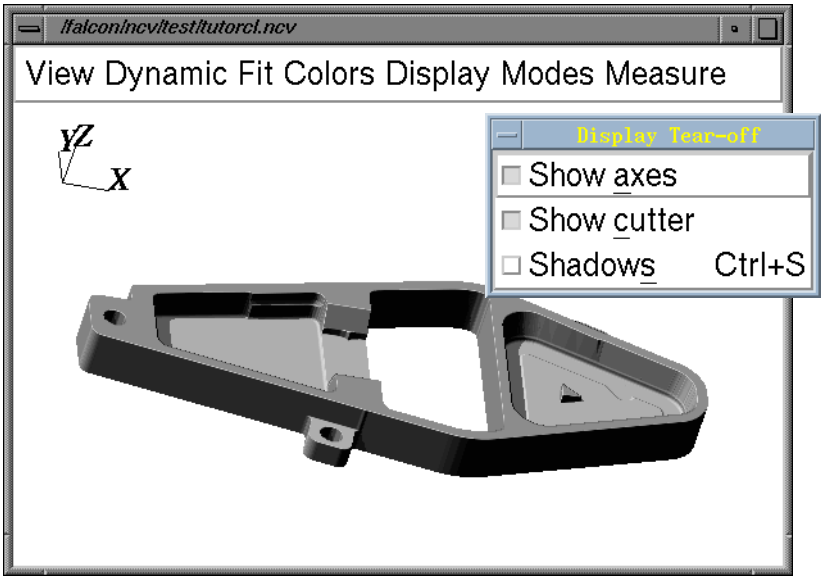


Figure 10-87 Displaying shadows

Playing Back the Recording of the Simulation

To play back the recording of the session, select Playback on your main control window. After asking for confirmation that you want to leave Simulation mode, your *Geometry Window* will disappear, and be replaced by one showing the starting view of the simulation.

Now go to the *Metal Removal Window* and select again *To End*, which displays the following menu:

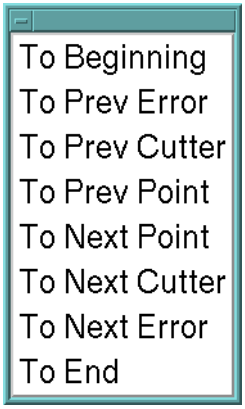


Figure 10-88 The *To End* menu

You can now set up the simulation to re-run to either the next point, the next cutter, or the next error, or to the end. At any point you can stop the playback, and run it backwards by going either to the beginning, or to a previous event. You will see that by stopping at any point and then stepping through, you can isolate any motion to a particular CL-ID.

To start with, select *To End*, and then select *Go* to start the playback. You will notice that the playback runs very quickly; this is because no calculations are being carried out, and the program is simply re-displaying the previously calculated simulation images.

If you want the playback to run slowly, simply hit the *Slow* button.

We suggest that after running through to the end, that you then run it back *To Beginning*, and then experiment with running it backward and forward as discussed above.

When you have finished with the playback facility, select the *Set up* button again; this will take you out of the playback mode. We can then go on to the second part of this tutorial.

Simulation Session - Part Two

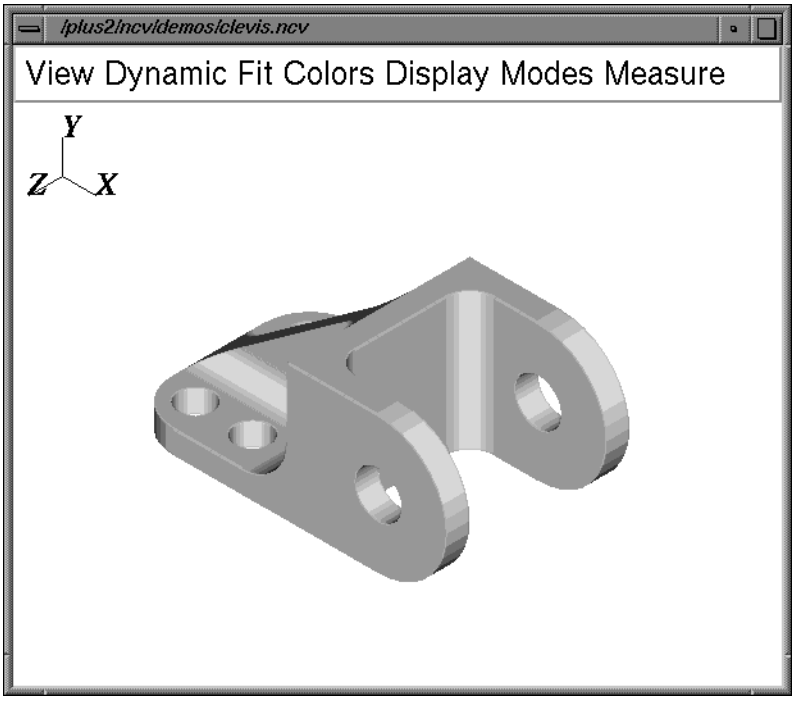


Figure 10-89

Comparison of the As-Machined Part with the Design Part

In this part of the tutorial you are going to check an as-machined part against an as-designed part. The machined part is that generated during the simulation of your NC program. The design part is going to be imported using an SLA format file, and then translucently superimposed on the manufactured part. All differences between the two parts will be highlighted.

Read an NC File for Comparison

Select **File** from your *Metal Removal Window*, and then select the *Read NC File* button to display the Read NC File panel. This time, select the **gouge.ncv** file, and select *OK*. This file has in it a part program that has deliberate errors, to show the functions noted above.

You can leave the other system settings, e.g., color switches, as they are for the moment, and we won't bother to record this session unless you want to.

In your view of the part, which is a clevis, select **View** and *Iso* to get an isometric view of the part, and then *Fit* the part into the window.

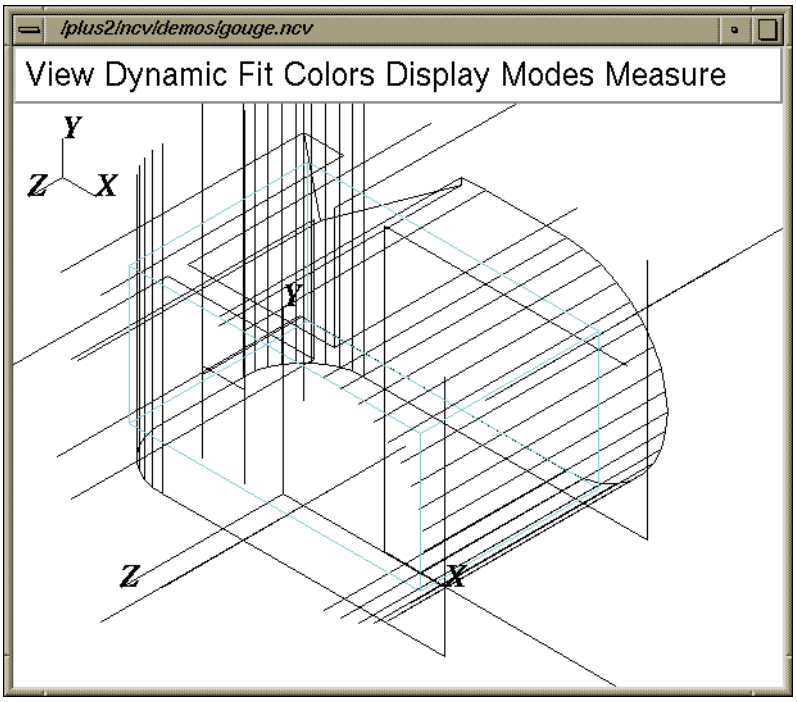


Figure 10-90 Isometric view of the clevis

Read in SLA File of the As-Designed Part

Now return to the *Metal Removal Window*, and select the **Model** button, which will display the following menu:

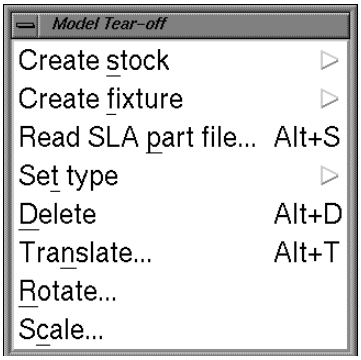


Figure 10-91 The **Model** menu

Select *Read SLA part file…*, and you will see a panel similar to the Read NC File panel which you have seen before, but this time set up to read files with the suffix **`.stl`**, which is the convention used generally for SLA files.

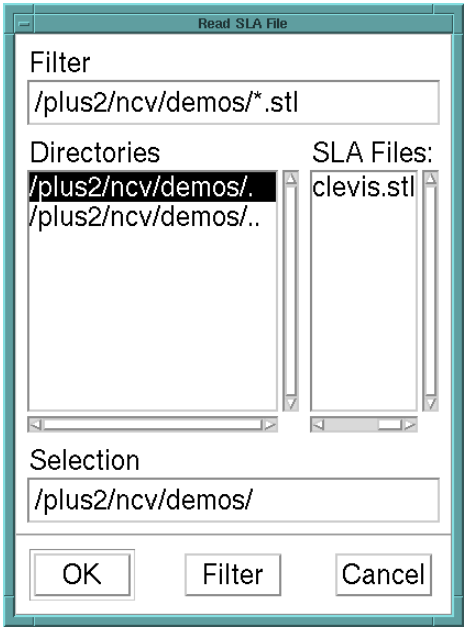


Figure 10-92 The Read SLA File panel

Select the file **`clevis.stl`**, and click *OK*.

After the file has been read, you will see the as-designed part superimposed in blue on the wireframe stock and model.

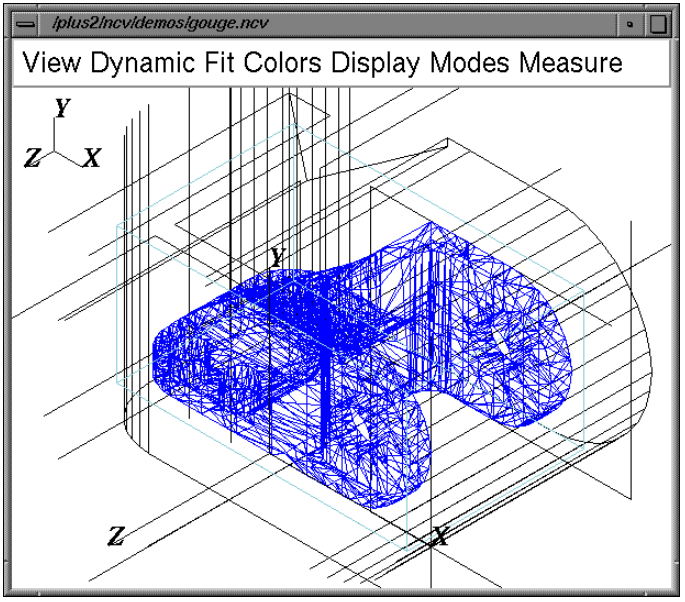


Figure 10-93 The as-designed part

Run the Simulation for the Comparison

Select *Simulate*, and then *Go*.

Compare the As-Machined Part with the As-Designed Part

When the simulation is complete, select the **Modes** button in your *Geometry Window*, which displays the following menu:

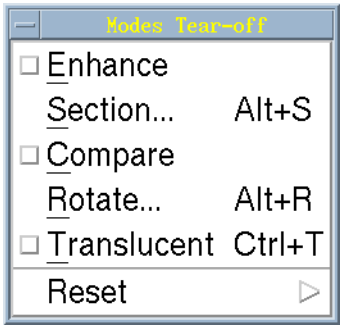


Figure 10-94 The **Modes** menu

Switch on ❑ Compare. First Cut will translucently overlay the imported as-designed model on the newly created as-manufactured model.

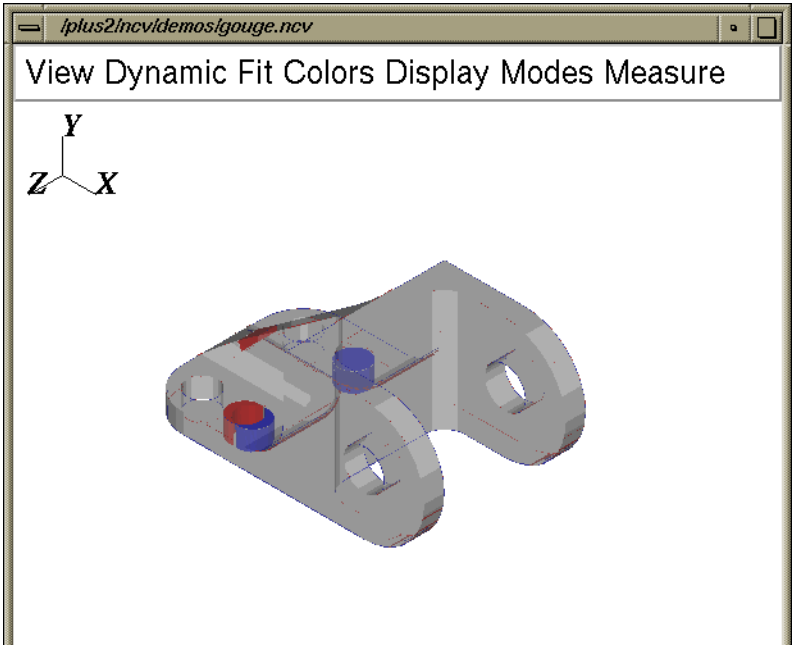


Figure 10-95 Comparing the as-machined part with the as-

designed part

Undercuts, where material according to the design part should have been cut away but hasn't, are highlighted in blue. For example, in the tutorial part, you will see a hole highlighted in blue; this is in the design part, but has not been cut in the manufactured part.

Overcuts or gouges, where material should not have been cut away, are highlighted in red. You will see one gouge highlighted in this fashion.

You will see one hole colored red on one side, and blue on the other. This shows that the hole is out of position: red shows the area into which the hole has moved, and blue shows where the correct limit of the hole area is.

You can if you wish go to the **View** menu and *Flip* the part to see the opposite side, although one of the virtues of the translucent image is that you can see all errors from any view.

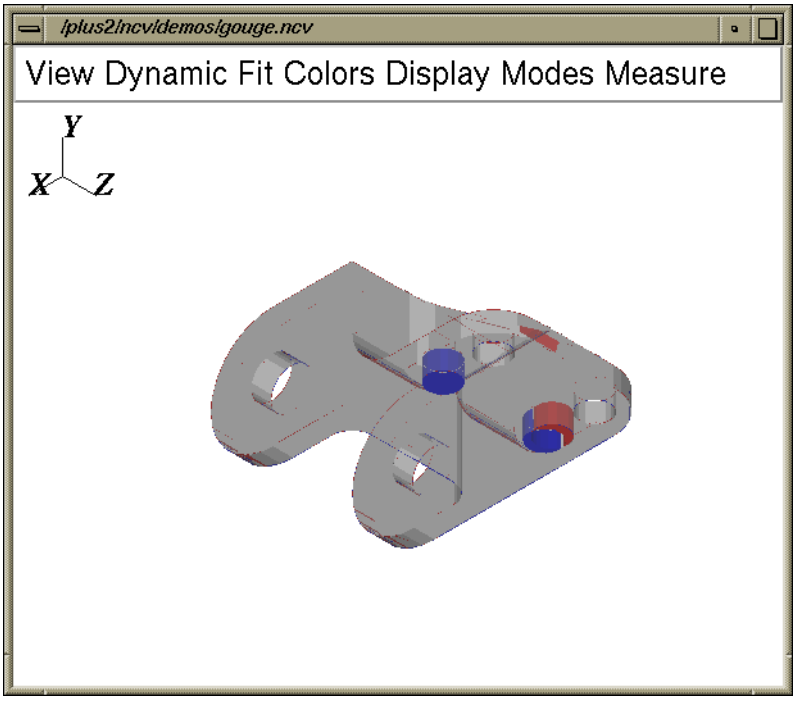


Figure 10-96 Flipping the part

This completes the tutorial for your introduction to First Cut. This introduction will have provided you with sufficient experience of the product and its interfaces, to be able to go through the *User's Manual* and look at the other capabilities of the product.

Other Production Facilities

It is worth noting some of the other production facilities that you may wish to use:

- ➢ Reading and writing intermediate results as Work in Progress (WIP) files

- ➢ Reading several files to be run unattended, sequentially, in batch mode
- ➢ Creating stock and fixtures to be used during the simulation
- ➢ Defining dimensions for a default cutter
- ➢ Subsetting the range of the simulation, to a section of the part or of the input NC file

Details of how to do the above are given in “First Cut Functions” on page -8.

Saving an Image of the Session

When the simulation is complete, select the **File** button in the *Metal Removal Window*, which gives you the **File** menu:

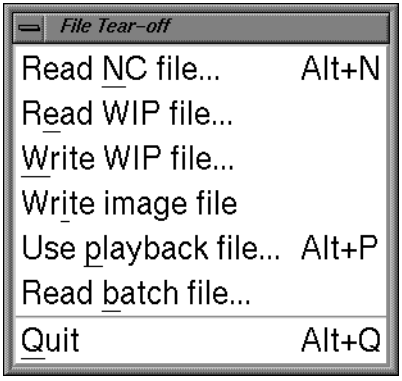


Figure 10-97 The **File** menu

Select the *Write image file* button. This creates an image file of your complete screen that is stored in your directory as a standard X-Windows **.xwd** file. Note that the name of the file being created is displayed in the message box on the *Metal Removal Window*.

You can create image files throughout the simulation automatically by using the facilities given in the **Auto** menu. For instance, you can create an image file whenever there is a cutter change.

Viewing Saved Images

To view an image file, create or go to another UNIX window, and log in if you have not already done so.

Search in the directory you have been using for the **.xwd** file you have just created, using by typing in the command:

```
ls *.xwd
```

This will list all the **.xwd** files in the directory.

Locate your new one, and then type in the X-Windows command:

xwud -in <filename.xwd><RETURN>

where **filename.xwd** is the name of the new file.

This will give you a display of the snapshot you created.

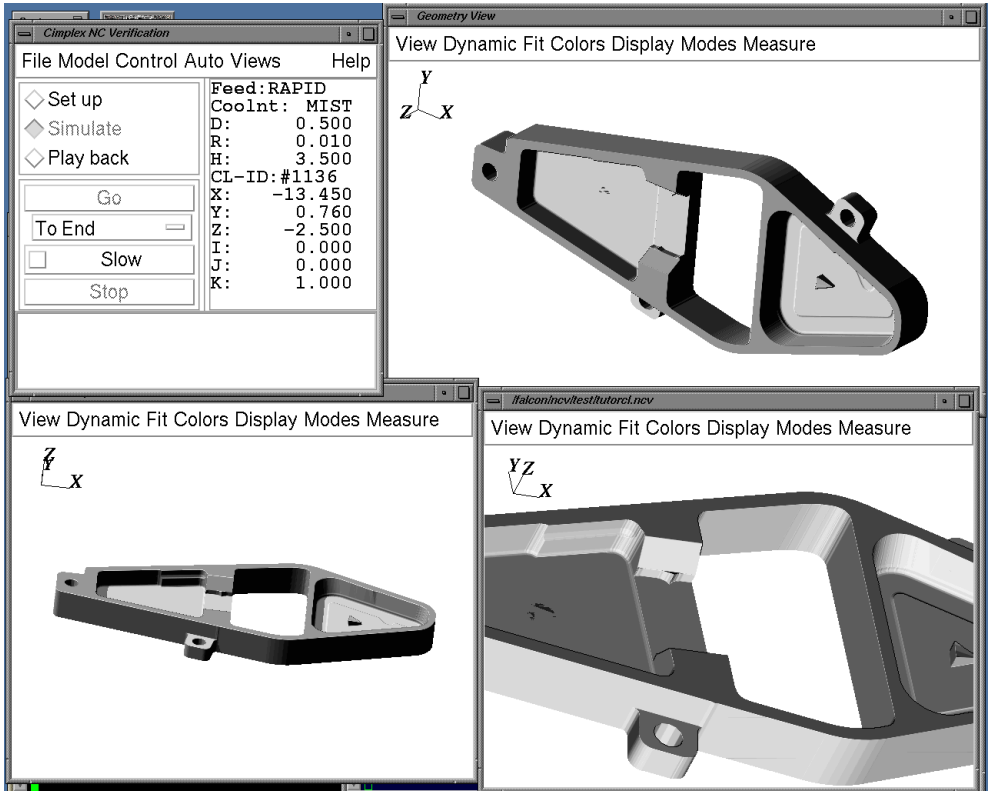


Figure 10-98 Snapshot

Click the left mouse button in the window to remove it.

Click the left mouse button in the window to remove it.

You can also incorporate the image files into documents, using any word processing or publishing software that accepts the **`.xwd`** standard format. This manual was produced using FrameMaker, and the screen images have all been produced using the **`.xwd`** utilities.

Exiting the First Cut **Simulation Session**

To exit the session, from your main window select the **File** button, and then select *Quit.*

Index

A

aax geometric type 4-13
abstract class facility 2-29–2-33
    astack 2-30
    concrete classes 2-29
    method, see method
acceleration 8-4
Accuracy 10-63
actions directory 3-10
activate procedure 2-38
add_gcode procedure 2-48, 8-27
add_mcode procedure 2-48, 8-28
affix command 6-8
affixing a model 6-8
application solutions 3-21
applications 2-16
apply operator 2-15
applyn operator 2-16
arc operator 5-2
ARRAY_BODY macro 3-34
array_of constructor 2-2
arrays 2-3, 3-30, 8-24
    array_create command 2-3
    carray 2-18
    components 1-8
    creating 2-3
    integer 2-3
    is_array function 2-10
    mismatch error 2-3
    passing to C 3-34
    sarray 2-4
    syntax for 2-3
as_type operator 2-21
as_view operator 2-28
ASCII file 3-5
assembly 7-18
assignment statements 1-9
atomic statements 1-9
authorization 3-1
Auto Menu 10-36
    Change color at cutter change 10-37
    Continuous display of cutter 10-38
    Enhance when writing image 10-39
    Record 10-39
    repaint 10-37
    Write image at cutter change 10-38
    Write image at error 10-38
Automatic 10-143
aux field 7-22

B

base_frame field 6-13
base_jv 6-14
Basic Structure for File Formats 10-77
batch file facility 10-21
Bezier curve 5-10
Bezier patch 5-11
bindings
    early 2-16
    late 2-16
block operator 5-13, 5-21
block, adding 5-13, 5-21
boolean type 2-4, 2-8
BORE 10-103
BOX 10-79
BREAK 10-79
break, pause 3-27
BRKCHP 10-109
bug tracking 3-29
build time 2-21
builds directory 3-10

C

C compiler 1-3
.c files 3-30
C language
    arrays 2-18
    build time 2-21
    calling C code from SIL 3-29–3-38
    carrays 2-18
    cast primitive 2-21
    char type 2-18
    crecords 2-17
    cstring type 2-19
    cstring_constant constructor 2-21
    data structures 2-21

data types 2-17–2-21
double type 2-18
***erb** type 2-17
float type 2-18, 3-30
importing C functions 3-30
int type 2-18, 3-30
pointer 2-18
records 2-17
short type 2-18
strings 2-19
copying 2-20
creating 2-19
mk_static_lstring function 2-20
null-terminated 2-19
printing 2-20
c_import command 3-30
call stack 3-23
CALL/CXCIR 10-80
canned cycles 8-18–8-23
disable 8-6
status, setting 8-6
cap, adding 5-4
carat (^) 2-18
case construct 1-9, 1-10
casting 2-21, 2-22, 2-28
CATIA 10-124
CBOX 10-80
Center 10-46
chain operator 5-13
Change color at cutter change 10-37
changer_link field 6-19
changer_mount field 6-19
Changing the View 10-140
Chip 10-148
$CIM environment variable 3-8
cim tree 3-8
Cimplex NCV Main Window 10-15
Information display 10-13
circle, adding 5-2, 5-10
circular interpolation 8-4
CL File Conversion 10-64
clamps 8-7
class 2-25
abstract, see abstract class facility
cutting_tool 7-7
mnode class 2-33
nc_machine, see **nc_machine** class
tool_changer 7-14
tool_holder 7-11
tool_lib 7-17, 7-22
classes function 2-28
CL-ID 10-58, 10-151
clock variable 2-34
closure 8-22
closures 2-43, 6-21, 7-24, 7-29, 8-24, 9-10
is_closure function 2-10
cltoncv 10-67
code
modules 3-8
organization 3-8
collision detection 7-29
Colors 10-47
Repaint 10-152
comment line ($$) 10-79
comodules file 3-19, 3-21, 3-22
syntax 3-19
Compare 10-51
compile command 3-15
compile_area command 3-15
compiling SIL code, see SIL: code: compiling
compound statements 1-9
concurrency 1-1, 2-34
cone operator 5-14
cone, adding 5-9, 5-14
const declaration 4-3
constants 1-8, 2-22
variants 2-23
constructed types 1-6, 2-2
Continuous display of cutter 10-38
Control Menu 10-31
Cutter limits 10-33
Multi-axis 10-36
Subset box 10-35
Subset range 10-35
Use entire NC program 10-36

coolant 8-7
COOLNT 10-81
Coolnt 10-14
Coons surface 5-8
coordinate system 4-1, 6-8–6-18, 8-16
  axes, mapping 6-9
  base coordinates 6-13
  base_jv 6-14
  moving a machine 6-10
  multiple work coordinates 6-13
  ref shape 6-11
  reference coordinates 6-11
  reference frame 6-11
  rotation 8-5
  SILSPEC coordinates 6-10
copy_gtable command 8-7
copy_mtable command 8-7
copyto procedure 2-20
Create fixture 10-28
Create stock 10-23
Creating Multiple Views 10-140
crecord 2-17
crt type 4-5
CSINK 10-112
current_authorization global 3-1
curve, adding 5-11
Custom CL File Conversion 10-77
CUTTER 10-81, 10-151
Cutter 10-74
Cutter Default Definition 10-73
Cutter Default Parameters 10-72
Cutter Definitions 10-65
Cutter Display Switch 10-139
Cutter limits 10-33
Cutter Types 10-73
cutting tool 7-3, 7-4
  class 7-7
  collision detection 7-29
  constructing 7-10
  cutter angle 7-7
  cutter offsets 7-26
  cutter revolution 7-32
  diameter 7-7
  flange 7-7
  flute length 7-7
  length 7-7
  material removal 7-30
  models 7-8
  retrieving 7-19
  spindle 7-32
  tip 7-7, 7-20
  tool holder, mounted to 7-11
  type 7-7
cutting_tool class 7-7
CYCLE 10-97
CYL 10-82
cyl type 4-6
cylinder operator 5-13
cylinder, adding 5-13, 5-23
cylinder, tabulated 5-7

D

d 10-123
data block 9-13
data flow 6-3
data types
  boolean type 2-8
  C data types, see C language
  cchar type 2-18
  constructed types 1-6, 2-2
  cshort type 2-18
  cstring type 2-19
  defining new 1-12
  gcode_info type 9-3
  integer type 2-8, 2-18
  lispob, see **lispob**
  lpoint type 3-34
  machine_status type 6-19
  metatypes 2-8
  mismatch error 2-3
  model data type 5-1
  ncv_sync_block type 9-12
  ntype, see **ntype**
  pipe 2-40
  point type 3-34
  pose 4-16

real type 2-8, 2-18
represented types
is_reptyp function 2-10
scalar 2-4, 2-8
semaphore type 2-38
shape 4-2
sreal type 2-18
string type 2-8, 3-34
symbols 2-49
system-defined 1-6, 2-4, 2-8
<type>p 3-34
universal, see **universal** type
user-defined 1-6, 2-6
data_variant operator 2-22
database 7-22, 7-27
deactivate procedure 2-38
debug_frame variable 3-26
debugging 3-23
call stack 3-23
error break 3-27
Error> prompt 3-23
menu mode 3-29
patching a function 3-25
pause break 3-27
ppause command 3-27
to_text_mode_on_error flag 3-29
trace back 3-24
deceleration 8-4
DEEP 10-105
default_gtable global 8-3
default_mtable global 8-3
define_method command 2-33
definitions 1-7, 1-11
dependencies 3-19–3-22
Determine CL-ID panel 10-151
dispatch procedure 2-16
Display 10-48, 10-138, 10-151
Show axes 10-48
Show cutter 10-48
Dithering 10-64
do_material_removal task 7-31
do_set_units expression 8-2
$$ 10-79
DRILL 10-100
Dynamic 10-43
dynamic list 2-2

E

early binding, see bindings: early 2-16
ellipse, adding 5-3, 5-10
ellipsoid operator 5-11
empty lists 2-3
emptysarray command 2-4
End 10-147
end effectors 4-10
Enhance 10-49
Enhance when writing image 10-39
ENVECT 10-82
environments
global 1-5
local 1-5
EOF 3-7
equivalent angle-axis 4-9, 4-13–4-15
erb type 2-17
Error 10-147
error break 3-23, 3-27
error logging 8-29–8-30
Error> prompt 3-23
Euler angles 4-9, 4-12
see also geometry
ev command 3-27
execute function 2-16

F

FACE 10-101
facet operator 5-4
facet, adding 5-4
FBOX 10-82
FCBOX 10-83
FCYL 10-83
FEDRAT 10-84
Feed 10-13
Feedrate 10-74
feedrate 8-6
field selectors 1-8
file

.sil extension 3-11
compiling 3-15
directories and organization 3-8
header 3-10
initialization 3-11
loading 3-11
reading & writing to 3-5
File Conversion Program 10-67
File Management 10-63
File Menu 10-15
Read batch file 10-21
Read WIP file 10-19
Use playback file 10-21
Write image file 10-20
Write WIP file 10-19
Filter 10-16
FINI 10-84
First 10-2
Fit 10-46
Fixture Definition 10-70
flange 6-10
Flipping 10-154
for statement 1-10, 1-11
Form 10-128
Format of ncvholder.lib 10-126
forward kinematics 6-15, 8-15
frame 4-2
reference 4-17
frame numbers 3-25
free_cstring procedure 2-20
FROM 10-85
frustrum operator 5-14
frustum, adding 5-14
function 7-24
definition 1-13
is_function function 2-10
function applications 1-8
function constructor 2-2
funnel operator 5-7
funnel, adding 5-7

G

G 10-120
g 10-122, 10-123, 10-124
G code
adding to an NC machine 2-48
closures 8-28
data type 9-3
executing 9-10
G table 6-21, 8-3, 8-24
customizing 8-27
grouping 8-25
modal 8-23
non-modal 8-23
reader 9-5–9-10
G code reader 9-5–9-10
G code translator 6-2
closure 2-45, 6-21
customizing 2-47
data flow 9-2
G table 6-21, 8-3
closures 8-28
customizing 8-27
g_functions type 8-24
garbage collection 2-17
gcode_info type 9-3
Geometry 10-138
geometry
definition 4-1
equivalent angle-axis 4-9, 4-13–4-15
Euler angles 4-9, 4-12
Z-Y-Z 4-12
frame 4-2
orientation 4-8
pose 4-1, 4-16, 6-11
position 4-4–4-7
Cartesian description 4-5
cylindrical description 4-6
spherical description 4-7
roll-pitch-yaw 4-11
terms 4-1
units 4-3
yaw-pitch-roll 4-9, 4-10–4-11
Geometry viewing window 10-11
Geometry Window Functions 10-41
Center 10-46

Colors 10-47
Display 10-48
Dynamic 10-43
Fit 10-46
Measure 10-55
Modes Menu 10-49
Pan 10-44
Rotate 10-51
Rotate XY 10-44
Rotate Z 10-44
View 10-42
Zoom 10-44
get_active_cutter function 7-19, 7-21
get_active_holder function 7-19
get_cutter_tip function 7-20, 7-21
get_holder_on_flange function 7-20
get_tlo procedure 7-28
global environment 1-5
globals 1-11
gluing objects 5-15
go command 3-27
GODLTA 10-85
GOHOME 10-85, 10-86
GOTO 10-86, 10-151
grid surface, adding 5-5, 5-22

H

h 10-123
.h files 3-10, 3-30
Help 10-40
Index 10-41
On Version 10-41
Tutorial 10-41
help command 1-16
help files, adding 3-13
help, getting 1-16
holder/cutter assembly 7-4
home directory 3-8
home position 6-14, 8-4
hyperbola, adding 5-3, 5-10

I

I/O 3-2
ASCII files 3-5
EOF 3-7
files, reading & writing to 3-5
read(x) 3-2
read_char() command 3-3
read_line() command 3-3
read_token() command 3-3
readln command 3-3
id 2-23
IGES
converting a model to a file 5-18
converting with text 5-17
Ignore holder and shaft 10-39
imoveto command 5-16, 6-12
import_tool_data procedure 7-25
importing C functions 3-30
in_frame operator 4-18, 4-20
Index 10-41
infix operators 1-8
Information display 10-13
CL-ID 10-14
Coolnt 10-14
D 10-14
Feed 10-13
H 10-14
I, J, K 10-14
R 10-14
X, Y, Z 10-14
inheritance 2-24, 2-26
init.sil file 3-12
initialization file 3-11, 3-12
Input name conventions 10-17
input/output, see I/O
input_types function 2-10
instantaneous block 2-34
instantaneous commands, see tasks
integer
constructor 2-2
data type 2-2
division 2-4
string, converting to 2-5
integer type 2-4, 2-8
interpolation mode 8-3

interpreted code 3-22
interpreter, SIL 1-5, 2-6, 3-2
inverse kinematics 6-15, 7-26
invert operator 5-14
is_array function 2-10
is_closure function 2-10
is_fail function 2-16
is_function function 2-10
is_list function 2-10
is_primitive function 2-10
is_reptyp function 2-10
is_task function 2-10
is_tclosure function 2-10
iteration statement 1-9, 1-10

J

joint vector 6-8–6-18, 7-28, 8-15

K

keyboard, reading from 3-2
kinematics 6-4, 6-8
    forward 6-15, 8-15
    inverse 6-15, 7-26

L

late binding, see bindings: late 2-16
lathe 6-19
lexicographical comparisons 2-5
Light 10-155
Light source 10-155
light source 10-45
link 5-19
Lisp 1-2
lispob 2-11, 3-34
    definition 1-6, 2-11
    symbols 2-49
list_of constructor 2-2
list_subtype function 2-10
lists 2-2
    dynamic 2-2
    empty 2-3
    is_list function 2-10
    null command 2-3
    type 2-3
LOADTL 10-86
local environment 1-5
lpoint type 3-34
lrecords 2-7, 2-22, 3-30
    passing to C 3-34
lstack 2-33
lstrings
    mk_static_lstring function 2-20
lstrings 2-5, 2-6

M

M code 8-24
    adding to an NC machine 2-48
    closures 8-28
    executing 9-10
    M table 6-21, 8-6
M table 6-21, 8-6
    closures 8-28
machine axes 6-8
machine coordinates 6-13
machine pendant panel 6-21
machine, see NC machine
machine_status type 6-19
Machining times 10-57, 10-150
Major 10-79
match operator 2-5
material removal simulation 7-30
Measure 10-55
    CL-ID 10-58
    Point 10-55
    Remove chips 10-59
    Time 10-56
Measure Time panel 10-150
Measure Volume panel 10-151
memory allocation 2-5
MES File 10-68
messages 2-41, 2-42
messages queue 2-40, 2-41
meta programming 1-1
Meta-Kinematics 6-4, 6-8
Metal 10-10

Metal Removal Setup panel 10-8
metaobjects 2-8
metatypes 2-8
method, abstract class
    define_method command 2-33
    fields 2-30
    primitives 2-33
    push method 2-30
    task, declaring as 2-33
    tmethod 2-33
    underflow 2-32
Minimum 10-73
Minimum Cutter Diameter Default 10-73
mk_aax command 4-13
mk_application function 2-16
mk_array_type function 2-10
mk_bsurf operator 5-8
mk_cap operator 5-4
mk_circle operator 5-2
mk_circular_arc operator 5-10
mk_cnsurf operator 5-8
mk_crt command 4-5
mk_cstring function 2-19
mk_cyl command 4-6
mk_ellipse operator 5-3, 5-10
mk_function_type function 2-10
mk_gsurface operator 5-5
mk_hyperbola operator 5-3, 5-10
mk_list_type function 2-10
mk_parabola operator 5-3, 5-10
mk_plsurf operator 5-5
mk_point command 4-5
mk_point operator 5-19
mk_pose command 4-16
mk_pspline operator 5-10
mk_psurf operator 5-11
mk_rbspline operator 5-3
mk_rbsurf operator 5-7
mk_rctcurve operator 5-2
mk_rsurf operator 5-23, 5-24
mk_rvsurf operator 5-6, 5-23, 5-24
mk_rvsurf_shape operator 5-9
mk_sph command 4-7
mk_static procedure 2-20
mk_static_lstring function 2-20
mk_ticker function 2-37
mk_universal constructor 2-13
mk_xyz command 4-12
mk_ypr command 4-11
mk_zyz command 4-12
mnode class 2-33, 6-21
model data type 5-1
Model Menu 10-22
    Create fixture 10-28
    Create stock 10-23
    Rotate 10-29
    Translate 10-29
modeling
    affixing a model 6-8
    constructors 5-1–5-11, 5-19–5-24
    examples 5-19
    IGES file, converting to 5-18
    IGES models, converting with text 5-17
    kinematics 6-4
    link example 5-19
    operators 5-14
    tool 7-25
    wireframe 5-13
Modes Menu 10-49
    Compare 10-51
    Enhance 10-49
    Reset 10-153
    Section 10-50, 10-152
module
    creating a new 3-14, 3-18
    definition 3-8
    version, creating new 3-17
modules 6-6
mount_tlib procedure 7-18
Move 10-45
move_handle shape 6-10
moveby command 5-16, 6-9
moveto command 5-16, 6-10
movies 8-30
Movies panel 8-30
MULTAX 10-87

Multi-axis 10-36
Multiple Viewports 10-63
my_class function 2-28

N

NC machine
    flange 6-10
    G code, adding 2-48
    joint vector 6-14–6-18
    M code, adding 2-48
    machine pendant panel 6-21
    spindle 7-6
    tasks 8-2–8-23
    tool library, mounting a 7-18
    tooling 6-18
NC simulator 6-2
    developing 6-4
    G code translator 9-3
    modules 6-6
    tooling assembly 7-2
NC tooling 7-3
nc_machine class
    changer_mount field 7-18
    constructing 6-22
    move_handle field 6-10
    pendant field 6-21
    ref field 6-11
    type declaration 6-7
ncreate_template command 3-20
NCV File 10-68
NCV File Format Specifications 10-77
ncv_index_tc task 8-9
ncv_index_turret task 8-9
ncv_null_link global 6-10
ncv_report_error procedure 8-30
ncv_sync_block type 9-12
new_cstring function 2-19
new_pipe command 2-40
newmodule command 3-12, 3-14
newproduct command 3-12, 3-17
NSIDES 10-87
ntype 2-9
    is_primitive function 2-10
    primitive operations 2-10
nul 2-28
null fields 6-10
null list 2-3
null terminated 2-28
Numeric convention 10-78

O

ob, see **lispob**
object
    casting 2-28
    data 2-8
    gluing 5-15
    metaobjects 2-8
object-oriented programming 1-1
offset vector 7-27, 7-28
offsets, cutter 7-26
On Version 10-41
operators 1-8
Optimal View 10-63
orientation, see geometry
Other Codes Supported 10-121

P

Pan 10-44
parabola, adding 5-3, 5-10
parametric curve 5-11
parametric surface 5-12
part coordinates 6-13
PARTNO 10-87
Pascal 1-2, 1-13
patching a function 3-22, 3-25
pause break 3-27
pcurve, adding 5-3
pcurvelist, adding 5-3
Performance 10-62
Physical Tool Changes 10-65
pipe operator 5-13
pipes 2-40
    adding 5-13
    creating 2-40
    messages queue 2-40, 2-41
    waiters queue 2-40, 2-41

pitch, see geometry
plane surface, adding 5-5
Point 10-55, 10-149
point type 3-34
point, adding 5-2
pointer 2-18
pointer management 1-2
polygon
    circular 5-4
    convex planar 5-4
polymorphism 1-2, 2-23
pose, see geometry
position, see geometry
Post Processor Statements 10-66
ppause command 3-27
PPRINT 10-88, 10-89, 10-90, 10-91, 10-151
PPRINT TRUEC 10-90
procedure 7-24
    applications 1-9
    definition 1-13
procedure constructor 2-2
process, syntax for 2-41
Processing 10-74
Product 10-4
product
    building 3-14
    creating 3-12–3-14, 3-17, 3-18
    help file, adding 3-13
    rebuilding 3-16, 3-17
    support only 3-21
    umodules file, including 3-20
Product Administration panel 3-18, 3-22
programming methods 1-1
protection 3-1
pseudo-code 1-3
pspline, adding 5-10
psurf_to_gsurf operator 5-5

R

radius compensation 8-4
RAPID 10-91
Rapid 10-146
rational B-spline surface 5-7
rbspline, adding 5-3
rbuild command 3-14, 3-17
rctcurve, adding 5-2
Read batch file 10-21
Read SLA file 10-27
Read WIP file 10-19
read(x) command 3-2
read_char() command 3-3
read_line() command 3-3
read_token() command 3-3
reader, G code 9-5–9-10
Reading 10-134
readln command 3-3
real type 2-4, 2-8
reals last rule 3-30
REAM 10-104
Record 10-39
records 2-7
    casting 2-22
    constructor 2-7
    crecords 2-17
    defining 2-7
    lrecords 2-7, 2-17
    mk_ prefix 2-7
    passing to C 3-34
    syntax for 2-7
ref shape 6-11
reference coordinates 6-11
reference frame 4-17, 6-11
reference system 4-1
referential equivalence 2-28
rel operator 4-17
remake command 3-16
REMARK 10-91
Remove chips 10-59
remove_view operator 2-28
rep_of function 2-10
Repaint 10-152
repaint 10-37
repeat statement 1-10
Reset 10-54, 10-153
Reset all 10-54
Reset light 10-54

Reset rotation 10-54
Reset section 10-54
Reset zoom 10-54
result_type function 2-10
roll, see geometry
ROTABL 10-92
Rotate 10-29, 10-45, 10-51, 10-153
Rotate XY 10-44
Rotate Z 10-44
Rotating 10-153
rotating turrets 6-19
rotation 4-3
ruled surface 5-23
run command 2-36
run queue 2-36
Russell's paradox 2-9
rvsurf shape 5-6

S

Sample 10-114
Sample Control File 10-117
Sample ncvholder.lib 10-127
Sample Stock Definition 10-118
sarray 2-4
scalar types 2-4, 2-8
sconst 2-22
    undefined_sconst 2-23
scope_out script 3-20
screen, writing to 3-5
Scroll bars 10-18
Section 10-50, 10-152
Sectioning 10-152
seg_pose frame 5-11
Select SLA file panel 10-9
semaphore 2-38
semicolon, use of 1-12
sequences 1-9
set_tlo function 7-28
Setting 10-144, 10-145
Setting up Recording 10-144
Shadows 10-48, 10-156
shape 6-11
shape data type 4-2
shape, adding 5-9, 5-24
Show axes 10-48
show command 4-17
Show cutter 10-48
signal command 2-39, 2-41
SIL
    arrays, see arrays
    class, see class
    code
        calling C code from 3-29–3-39
        compiling 3-8, 3-14–3-17
            rbuild command 3-17
            remake command 3-16
        debugging, see debugging
        importing C functions 3-30
        interpreted 3-22
        recompiling 3-16
    data types, see data types
    definitions 1-11
    environment 1-3
    expressions 1-3, 1-7
    help 1-16
    implementation 1-2
    interpreted language 1-5
    interpreter 2-6, 3-2
    statements 1-9
    terms 1-8
    uncompiled code 1-3
SIL I/O 3-2
sil_load command 3-11
SILSPEC
    coordinates 6-10
Simulation 10-149
simulation 6-18
Simulation and playback control 10-156
Simulation Setup panel 8-30
SLA 10-118
SmallTalk 1-2
Solid cutter 10-38
spatial geometry, see geometry
Special 10-122
specialize_to operator 2-27
sph type 4-7

sphere, adding 5-23
SPINDL 10-92
spindle 7-6, 7-32, 8-6, 8-18
splice operator 2-29
SPPROF 10-94
SPROF 10-94
sspa script 3-14, 3-18
stack 3-24
start command 2-36, 3-17
start up 2-21
statements 1-7, 1-9
    atomic 1-9
    compound 1-9
    constructors 1-9
    iteration 1-10
static 2-19
static polymorphism 1-3
station number 6-19
status 6-19
Stock box (auto) 10-70
Stock Box (specified) 10-69, 10-70
Stock Definition 10-69
Stock Profile Sweep 10-70
STOP 10-86, 10-94
Stopping 10-146
string type 2-4, 2-8, 3-34
strings 2-4
    C strings 2-19
    comparisons 2-5
    concat_onto procedure 2-6
    conversions 2-5
    copy function 2-6
    cstring type 2-19
    cstrings
        copying 2-20
        creating 2-19
        printing 2-20
    equal function 2-6
    find function 2-6
    float2lstr function 2-6
    integer_to_string command 2-5
    length 2-5
    lowercase operator 2-6
    lstr_to_str function 2-6
    lstrings 2-5, 2-6
    match operator 2-5
    mk_lstring function 2-6
    mk_static_lstring function 2-20
    null-terminated 2-19
    real_to_string command 2-5
    select function 2-6
    string_to_integer command 2-5
    string_to_real command 2-5
    substring function 2-6
    to_string function 2-6
struct declaration 3-34
STVECT 10-94
subroutines 9-12
Subset box 10-35
Subset range 10-35
subtype function 2-10
supertypes 2-8
supmodules file 3-19, 3-21, 3-22
    syntax 3-19
support only builds area 3-21
surface of revolution 5-6, 5-23
swept volume 7-30
symbols 2-49
    data type 2-49
    id 2-49
    identifiers 2-49
synchronized cutting 9-13–9-17
Syntax for Each Control File 10-69
system-defined types 1-6, 2-4, 2-8

T

TAP 10-102
task
    closure 6-21
tasks
    closure 9-10
    communication 2-40
    instantaneous commands 2-34
    is_task function 2-10
    machine dependent 8-8
    machine independent 8-2

messages 2-41
pipes 2-40
messages queue 2-40, 2-41
waiters queue 2-40, 2-41
run queue
placing tasks in 2-36
scheduler 9-6, 9-10, 9-12
signal command 2-39, 2-41
start command 2-36
synchronization 2-38
tclosure type 2-46
temporal commands 2-34
tool changers 8-8
wait command 2-42
wait operator 2-38, 2-41
tb command 3-26
tbn command 3-26
tclosure 2-46, 2-48
is_tclosure function 2-10
tclosure type 2-46
temporal commands, see tasks
terms 1-7
Text Mode 1-4, 2-36, 3-23, 3-29
THRU 10-111
tickers 2-37
tilde 10-106
Time 10-56, 10-150
time
commands, see tasks
simulated 2-34, 2-36
TLAXIS 10-95
TMARK 10-86, 10-95
tmethod 2-33
to_cstring function 2-19
to_text_mode_on_error flag 3-29
to_view operator 2-28
token 3-2
Tool 10-74, 10-125
tool
adaptor 7-3
changer 7-3, 7-4, 7-6
chain type 7-16
chain-type tool magazines 8-9
class 7-14
constructing 7-16
holder mount position 7-14
machining center 8-8
rotating turrets 8-9
station 7-14, 8-9
tasks 8-8
turning machine 8-9
turret type 7-15
cutting, see cutting tool
holder 7-3, 7-4, 7-17
class 7-11
constructing 7-13
cutting tool, mounting 7-11
flange 7-11, 7-20
mount position 7-11
retrieving 7-19
type 7-12
holder/cutter assembly 7-6
offsets 7-27
turning 7-3
tool library 6-18–6-19, 7-4, 7-17–7-25
auxiliary data 7-24
class 7-17
database, integrating 7-22
tool magazine 7-6
Tool Setup panel 7-10
tool_changer class 7-14
tool_holder class 7-11
tool_lib class 7-17, 7-22
TOOLNO 10-86, 10-96
top bar 3-13
trace back 3-24, 3-26
Translate 10-29
translator, G code, see G code translator
Translucent 10-53
tube operator 5-6
tube, adding 5-6
TURRET 10-86, 10-96
turret lathe 7-5

Tutorial 10-41, 10-132
type definitions 1-16
type_of operator 7-24
<type>p type 3-34

U

umodules file 3-12, 3-20
unary operators 1-8
undefined_sconst 2-23
underflow, method for 2-32
universal type 2-13, 3-26
Universe coordinate system 4-16
Use entire NC program 10-36
Use playback file 10-21
User 10-7
user-defined types 1-6, 2-6

V

V 10-76
variable declarations 1-15
variables 1-8
    global 1-11
variants 2-23
version, creating a new 3-17
View 10-42
View Selection 10-139
Viewing 10-147
views 2-28
    as_view operator 2-28
    manipulating 2-28
    referential equivalence 2-28
    remove_this_view operator 2-28
    splice operator 2-29
    views function 2-28
Views Menu 10-40
Visual SIL Window 3-13
Volume 10-60, 10-151

W

wait command 2-42
wait operator 2-38, 2-41
waiters queue 2-40, 2-41
while statement 1-10
widgets 2-33
wireframe models 5-13
work coordinate system 8-16
work coordinates 6-18
World 4-16
Write image at cutter change 10-38
Write image at error 10-38
Write image file 10-20
write statement 3-5
Write WIP file 10-19

X

xyz geometric type 4-12

Y

yaw, see geometry
yaw-pitch-roll, see geometry

Z

Zoom 10-44, 10-46
Zooming 10-154
Z-Y-Z Euler angles 4-12
zyz geometric type 4-12